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CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

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LOOKING FOR A JOB? Control *carries the best jobs going in instrument and control engineering.* **SEE PAGE 188 AND ONWARDS**

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FEBRUARY 1961 VOL. 4 No. 32 CONTROL

The coming men

ORGANIZATIONS, studies, businesses and industries may, in today's jargon, be divided into 'horizontal' and 'vertical' categories. Members of the Institution of Mechanical Engineers have during recent weeks been invited to register themselves in new groups under these two main headings. Horizontal subjects, they have been told, are generally interesting to members in any branch of engineering, while vertical subjects appeal mainly to those who work on them. According to the Institution, mechanical engineering science is divided horizontally into six compartments, one of which is Automatic Control. If other bodies follow suit, the various Automatic Control and other horizontal groups will meet at the edges, and there at least the boundaries between the institutions will tend to disappear.

Last month, at an informal discussion (reported at some length on p. 88), there was a tussle over the relative virtues of mechanical and electrical (more particularly electronic) engineers, and although the exchanges were made in good humour, it seems a pity to us that such an argument could have arisen at all. Professional engineers, faced by real problems, do not drop impermeable barriers between mechanical and electrical solutions. It is deplorable that the men who are concerned with dynamic rather than with static engineering should remain separated into apparently competitive camps. If an engineer is truly entitled to the epithet 'professional', he will make his mechanisms move by means of natural magnets, electromagnets, springs, gravity, compressed fluids, or whatever else comes most effectively to hand. Engineering itself must, by definition, stretch as far horizontally as any of its parts.

We are thus led to ask what is the horizontal extent of our own subject. It has more than once been suggested in this journal that control engineering is analogous to such 'instituted' activities as mechanical, electrical and chemical engineering, etc. In last month's issue Professor John West went further than that. He said in effect that the horizontal spread of 'control' is as broad as that of engineering itself, and he condemned as basically wrong any comparison with the accepted subdivisions. Professor West drew attention to the educational problems entailed, and these are discussed afresh this month by Mr W. F. Lovering on p. 83. Here, obviously, are serious questions for all who are concerned with the guidance of young entrants to engineering.

Some of those young men had sound advice from Mr E. S. Sellers a few weeks ago. In his presidential address to the Junior Institution of Engineers Mr Sellers spoke of the 'essential unity' of engineering. We entirely endorse the view that where there is fundamental unity it should be fostered and preserved (although in some engineers the sense of it is never awakened, or is too weak to endure). If we are asked how, after such a declaration, we can still urge (as we have done repeatedly in the past) that a special institution is necessary for control engineers, we cannot find a better way to answer then by drawing on Mr Sellers' address. He spoke first of people who 'insist on wearing the label of their initial training and go through life maintaining that they are chemists or physicists or mechanical engineers or whatever their initial qualification has entitled them to call themselves'. Then, recalling the time when he first went to work in the United States, Mr Sellers went on to tell how puzzled he had been when certain people there were described as engineers. They were doing everything from laboratory experiments on chemical reactions to the design and operation of large plants. It was soon pointed out to him that the word 'engineer' was applied to a scientifically trained professional man with a flexible mind, a man who could assess almost any problem objectively. Inevitably individuals developed specializations, but these were often associated with particular problems, and people seemed quite ready to develop new specializations when assigned to different problems.

There you have it. Nobody at any instant can keep his eye on everything. Specialization is inescapable, and special interests must be served (hence the need for specialized bodies), but your professional engineer can move around. It may well be that Professor West is right, and that control engineering is so important that every professional engineer should be acquainted with it. Nevertheless, like other such all-pervasive subjects (mathematics, for instance), control or systems engineering is bound to produce its single-minded devotees, and they are the ones who must lead its advance. At the moment, unhappily, they are still scattered and scarce in this country: but they are the coming men.

VIEWPOINT

A. H. Cooper—Technical Director of E.M.I. Electronics—in an open letter to the Editor, warns that you can hire consultants and buy information, but . . .

YOU CAN'T BUY COURAGE

My dear Conway,

You and I gossiped too late after the I.Mech.E. Conference on Computer Reliability: the result was that I missed my train at Waterloo and had a half-an-hour's wait, which gave me plenty of time to look at that poster which spans two platforms and vain-gloriously proclaims that 'British Shipbuilding Leads the World'. Coming so soon after Freebody's opinions at the conference—voiced from the lofty heights of the Treasury—about the perils of complacency, I found myself wondering why this sort of poster is put up and is believed in.

Several *Viewpoints* have been devoted to the question of why it is so difficult in Britain to get new ideas accepted and get them converted into usable hardware. I think that poster typifies one of the reasons. There are far too many people who are convinced that everything is all right and that there is no need to change. There are far too many people who are convinced that everything would be all right if only the other so-and-so's would play their part.

You get a contented feeling when you think that We Lead the World. But the man who really does lead the world is discontented; being a leader gives no comfort (except perhaps in retrospect) but it demands courage. Courage to imperil this year's balance sheet for what you believe in for the future; to put your trust in new ideas which cut across the experience of your lifetime; to go ahead when realists tell you to water down specifications or put back dates. ('Realist' is usually an alias adopted by a coward.) You need courage to go ahead when prudence bids you sit on the fence—until you're shamed into action and have to snatch at a prefabricated and often inappropriate solution.

You can't buy courage; you can buy information and advice from consultants, but the choice between courage and timidity is yours. Consultants can write specifications and assess and appraise and inspect, but the only way they can save you from emotional conflict is by prescribing something foolproof and pedestrian. I'm sure that courage is the missing intangible thing that *Viewpoints* have been groping after; and we all want it, whether we be suppliers or customers, management or designers, research workers or installers; and its presence or its absence contagious.

You can't buy this courage; where are we to get it from? Frankly, I believe it's within all of us; if we can but bring it out. Our ancestors had it in plenty when they went adventuring; but they had an urge to adventure so as to lead the world.

The first Elizabethans didn't put up posters about leading the world; they went out and fought the Spaniards, knowing that they needed to do it and could do it, and that unless they did they wouldn't survive. Was there ever a closer parallel?

Yours sincerely,

A H Cooper.

LETTERS to the EDITOR

Too wide for undergraduates

SIR: Proposals for establishing Control Engineering as a primary discipline, or of integrating it throughout engineering courses seem to assume a level of knowledge in the early years of an undergraduate course which is in practice never reached.

It has been suggested that no single lecture to undergraduates should contain more than two new concepts and preferably not more than three new words to be defined. If therefore, it is desired to introduce the concept of closed loop control, it is desirable that the individual parts of the loop should be, if not familiar to the student, at least not novel. This consideration suggests that the first introduction of the subject should occur in the second, or even in the third year of the Diploma in Technology course. The question of the breadth of treatment of the subject can be settled only with reference to the type of engineers it is hoped to produce bearing in mind that a graduate is not an engineer until he has had several years of experience in industry.

Industry's present needs seem to call for several types of special knowledge; the "research engineer" should open up new fields of automatic control; the "applications engineer" should be able to apply the result of research to practical problems and the "production engineer" should be able to design the parts of a control system for economic manufacture. In addition there is the division between process control and servomechanisms and the variety of electrical, mechanical and electromechanical control methods to be considered.

The whole field is too wide to be included in the normal undergraduate course; the electrical engineering degree course gives a graduate a sufficient understanding of the problems of design of electrical machines and electronics and magnetic power amplifiers for him to specify such elements for control loops without asking for the impossible or the ridiculously expensive. His knowledge of chemistry or mechanical amplifiers and of vibration is, however, very limited. The chemical engineering graduate has a better understanding of the chemical problems involved in a process, but has little knowledge of electronics. The mechanical engineering graduate has a better knowledge of mechanical problems, but usually knows little of electronics.

One approach to the problem is to introduce control engineering as a final year subject. In my Department Automatic Control and Instrumentation may be offered in place of telecommunications in the Diploma in Technology course. Graduates from this course will have a sound grounding in automatic control theory, but cannot in the limited time available cover more than a fraction of the wide field.

Another solution lies in postgraduate courses. Several colleges including my own offer one year courses which may be attended by graduates in chemical engineering, mechanical engineering, electrical engineering and physics. Ideally a student should attend such courses after one or two years' experience in industry and several such students have attended my course. Only a few firms, however, seem willing to release a young graduate for the nine months of the academic year. Industry generally has accepted the necessity for training schemes to produce the engineers which it will need; only in the field of control engineering is organised training the exception rather than the rule. Many firms seem content to recruit their control engineers from other firms in the industry, thus of course, producing a disturbance which propagates around the whole closed system.

Sufficient feedback of students from industry to postgraduate courses could produce the exponential growth of trained control engineers which this country needs. Only when the numbers so produced have risen appreciably does it seem likely that an Institution of Automatic Control could be established to advance research in the manner visualized by Dr. Westcott.

Battersea C.A.T. W. F. LOVERING

● *When Dr Westcott called for an Automatic Control Research Establishment in our November issue last year, he cited atomic energy and aeronautics as fields already having research establishments. Those establishments grew very rapidly from small beginnings, themselves serving an educational function and helping to increase the national manpower required for the new industries. Something similar might seem specially necessary for automatic control, since industry is indeed so backward.*— EDITOR

Completely under control

SIR: My sympathy and interest was evoked by the first paragraph of "Pick-off" in the December number of *Control* and its writer's complaint about "that wretched *g*". There is really no need for the confusion.

It all begins with the omission of a "proportional control factor". The second law of motion expresses a proportionality viz. force proportional to rate of change of momentum. This, applied to one piece of substance, i.e. one mass, becomes a proportionality between the force (the cause) on the one hand and the product of the size of the mass and its acceleration (the effect) on the other. This is a proportionality between input and output.

Had a constant of proportionality been inserted and retained, much of the confusion would never have arisen. Its ommission was, however, justified by the plea that if suitable units were chosen the constant is unity and can be omitted. Just try working out the equation of a proportional control system on the same basis and see where it gets to! However, there it is, so we accordingly write the equation of the second law as $f = ma$, where f, m and a stand respectively for the force, mass and acceleration, the symbols standing for the actual physical quantities. This latter point is important. When we come to a calculation each symbol is, accordingly, replaced by a number *and* its appropriate unit or units. This too is important.

Now, in selecting units for the three quantities we are free to choose any two of them arbitrarily but we must not do this for the third. Our hands are tied by our omission of the constant. The third must consequently be derived from the other two. Even so there is no limit to the number of choices which could be made for the three quantities. However it is desirable that our units should bear some relation to the weights used in the world of commerce. If we take the weight of a certain lump of platinum as our unit of force we may write this as 1 lbf. (The Lb of the Stroud system is even better!) This then is the unit by which we express weights, forces and stresses.

Next it seems sensible to take the mass of the same lump as our unit of mass, which we write as 1 lb. Now the concept of mass is slightly more abstract than that of weight but the realisation that is is almost synonymous with inertia helps us to distinguish it from weight. In physical reality

mass and weight are as different as the proverbial chalk and cheese. To find out what is to be the derived unit i.e. of acceleration, we must ask ourselves the question "What acceleration will be produced by a force of 1 lbf acting upon a mass of 1 lb?" The answer is delightfully simple "Drop it and see!" It turns out to be 32·2 ft/s². The fact that this figure differs slightly from one place to another is, forunately, of little practical significance and need not concern us here. We are now ready to write the equation in terms of these units: $1\ \text{lbf} = 1\ \text{lb} \times 32{\cdot}2\ \text{ft/s}^2$.

There are two schools of thought which object to showing 32·2 in their calculations, each claiming to have an absolute system, but in reality all that has been done is to hide the 32·2 under the name of a new unit. Thus the offending number may be moved to another place and the equation written as $1\ \text{lbf} = 32{\cdot}2\ \text{lb} \times 1\ \text{ft/s}^2$. Now call the 32·2 lb mass by another name, the slug, and we have

$$1\ \text{lbf} = 1\ \text{slug} \times 1\ \text{ft/s}^2$$

Alternatively, take the 32·2 to the other side of the equation and introduce the poundal and we have

$$1\ \text{poundal} = \frac{1\ \text{lbf}}{32{\cdot}2} = 1\ \text{lb} \times 1\ \text{ft/s}^2$$

Both of these devices, although much used, are somewhat artificial in that each introduces a new unit, the one of mass the other of force, neither of which really exists! Our next step gives the coup-de-grace to the terror. By dividing our first equation in turn by the R.H.S. and the L.H.S. we obtain two expressions each equal to unity

$$\frac{1\ \text{lb/s}^2}{1\ \text{lb} \times 32{\cdot}2\ \text{ft}} = 1 = \frac{1\ \text{lb} \times 32{\cdot}2\ \text{ft}}{1\ \text{lbf s}^2}$$

Then, remembering that the second law is the only bridge by which we can cross from the units of mass acceleration to units of force and vice versa, we use one of these unity expressions, whichever is appropriate. Logically this is above question, since multiplying any quantity by unity, or its equivalent, does not alter its value.

A simple example must suffice.

$$f = ma = 50\ \text{lb} \times \frac{20\ \text{ft}}{\text{s}^2} \times \frac{1\ \text{lbf s}^2}{1\ \text{lb} \times 32{\cdot}2\ \text{ft}}$$

$$= \frac{50 \times 20}{32{\cdot}2}\ \text{lbf}.$$

This procedure is foolproof—and quite painless! The slight extra trouble in writing down all the units and cancelling out the unwanted ones pays handsome dividends in the certainty with which the conclusion is reached. No more throwing in a 'g' hoping that it goes into the right place. The process is completely under control from first to last. Moreover it is just as easy to use any combination of units, pounds force or poundals, pounds mass or slugs, or their corresponding metric equivalents, just as they arise, and to come out correctly in any desired combination of appropriate units with an ease and facility which is a surprise to those to whom units had formerly been a terror.

Southampton University C. H. HELMER

Space-vehicle attitude

SIR: I was interested to read in your August 1960 Volume 3 No. 26 Page 111, reference Space Vehicle Attitudes to find a recent development using mass ejection for attitude correction.

It would appear to me that although this is probably an elegant method whilst the vehicle is being driven by a jet it might be an unnecessarily wasteful method when the vehicle is in orbit or has reached its maximum travelling speed.

For angular orientation a double opposed gyroscopic system could be used without any loss of mass. With gyro wheels running in opposition mounted on two separate but co-axial two-axis gimbal systems, movement about say the *X* axis could be obtained by the application of self contained precessional forces by a jack applied between the two gimbals to exert a torque about the *Y* axis resulting in the gyroscopes precessing about the *X* axis and taking the vehicle with it. A duplicate jack system could be arranged in quadrature to provide control movement about the *Y* axis. The exhaust from the jacks to the discharge tank conserves the fluid ready for re-compression by the vehicle's auxiliary engines.

Lewisham, S.E.13 JOHN TINDALE

● *Mr Robert S. Scher writes: 'Mr. Tindale's comments regarding space vehicle attitude control schemes are interesting and well taken. Applying torques to the gyro gimbals and taking advantage of the resulting precession of the gyro's angular momentum vector appears to be an effective, efficient means of attitude control.*

'A practical difficulty that perhaps might be involved in Mr. Tindale's scheme is the necessity of having the jacks mounted on the gimbals, and hence rotating with them relative to the vehicle. This would require rotating seals of some sort in order to supply the jacks with pressurized fluid and also to drain them. Applying the gimbal torques by some electromagnetic means would help solve this problem, particularly if the electrical power source (batteries) were carried on the gimbals with the electromagnetic actuator.

'Of course, an important consideration is the total initial weight of the orbiting vehicle, and the total length of time required for operation of the attitude control system. If constant changes and adjustments in attitude are necessary, then the amount of mass carried along for ejection purposes can become prohibitive, and the gyro system would seem more attractive. If however, only an initial, but precise, adjustment is required, a mass ejection system for coarse adjustment, and motor driven wheels for fine adjustment may be the better solution.'

—EDITOR

Invariance

SIR: I am very glad that your journal has started publishing papers devoted to the invariance theory, such as "Back and forward" by G. M. E. Williams in May 1960, "Theory of invariance" by L. Finkelstein in November 1960, and my own paper in December 1960. This theory is a very important and progressive one.

Unfortunately I had no possibility to correct my own mistake in the paper while correcting the galley proofs. The right expression for equation (1), p. 99, is:

$$\delta_c = \frac{d\alpha_c}{\alpha_c} = \frac{1}{\alpha_c} \times \left(\frac{\partial \alpha_c}{\partial \alpha_1} d\alpha_1 + \frac{\partial \alpha_c}{\partial \alpha_2} d\alpha_2 + \frac{\partial \alpha_c}{\partial n_0} dn_0 + \frac{\partial \alpha_c}{\partial m_0} dm_0 \right)$$

$$= \frac{1}{S}\delta_1 + \frac{\alpha_2 n_0}{S}\delta_2 + \frac{\alpha_2 n_0}{S}\delta_{n0} + \frac{\alpha_1 \alpha_2 m_0}{S}\delta_{m0}$$

where stiffness $S = 1 + \alpha_2 n_0 + \alpha_1 \alpha_2 m_0$.

Or, when $\omega_0 = f_3(n_1 n_2)$:

$$\delta_{\omega_0} = \frac{d\omega_0}{\omega_0} = \left(\frac{\partial f_3}{\partial n_1} \right) \frac{n_1}{\omega_0} \delta_{n1} + \left(\frac{\partial f_3}{\partial n_2} \right) \frac{n_2}{\omega_0} \delta_{n2}.$$

The word "stiffness" in the sentence on p. 97, line 21 from below, is to be omitted. The rest of the content is correct in general.

The paper, in corrected and to some extent changed form, will be published in our Ukrainian journal "Avtomatika", N5, 1960, where there are always short summaries in English and Russian.

Thank you very much for giving me the opportunity to promote the invariance theory among English-speaking people. My kindest regards to all those whom I met in your remarkable country.

Kiev, U.S.S.R. A. G. IVAKHNENKO

● *Professor Ivakhnenko's original correction was unfortunately delayed in the post and we received it too late to put the article right before publication.*

We know that we can speak for many others, as well as ourselves, when we warmly return Professor Ivakhnenko's greetings.—EDITOR.

This year's physics show drew the usual crowds. Here is a control engineer's review of the ideas displayed

'Phys. Soc.' 1961

by **G. M. E. WILLIAMS**
Northampton C.A.T.

Fig. 1 Coefficients of a complex transfer function can be read quickly and directly from dials on the centre panel of this computer

THE BRITISH SCIENTIST AND DEVELOPMENT ENGINEER has come to regard the Annual Exhibition of Scientific Instruments and Apparatus as a fixed point in the calendar and to refer to it as the 'Phys. Soc.'. I suppose this use of the abbreviation for the Physical Society follows from the librarians' reference to the 'Proceedings of the Physical Society' as 'Proc. Phys. Soc.' The Exhibition has been promoted for many years by the Society but this year, for the first time, the sponsors were the recently-formed joint body, The Institute of Physics and the Physical Society. Nevertheless, this Exhibition was described in the Official Handbook as the 45th, and indeed such continuity as we have all come to expect in the nature of the event has not been disturbed. A change of sponsors' title on the Handbook and admission tickets, and a slightly surprising omission of an official opening by an eminent physicist—these were the only obvious departures from past practice. Little else could be expected, in view of the fact that arrangements for the Exhibition had to be completed well ahead of opening day.

This year there were 146 stands and about 1600 exhibits on them, these figures being comparable with the most recent years' Exhibitions. The event is unique to this country, at least for a display on such a scale, and as it has evolved from what now appears the quite distant past, with little change in substance in the conditions which govern the acceptance of an exhibit, the effect would in general be difficult if not impossible to conjure up in other scientific fields here, or in its own field abroad. The 'Phys. Soc.' is in many ways akin to other British institutions, conceived in an earlier and different situation, partly changed by a process of evolutionary adaptation including change of habitat, but retaining the original idea. This was and is that the exhibits shall demonstrate the current practical work in the laboratory and in the field by presentation and demonstration of the physical instruments and apparatus with which the body of scientific knowledge is increased. Originality of an exhibit is essential, so repeat appearances without change are disallowed.

Originally, no doubt, the great and the very few who worked in physics found the event an essential and stimulating engagement, a vital form of communication. Today, part-drowned by the flood of published work, part-drugged by the information officers, and doomed anyway to be informed eventually by a heap of punched cards or a file computer, *h. sapiens sc.* can still take a short cut by visiting the Physical Society Exhibition and find quickly something new and stimulating in his own field. I doubt whether he would regard this advantage as an essential, as I am in no doubt the early exhibitors and their visitors did. He also has to exercise all his powers of patient investigation to run the prizes to earth. I would ask those who grumble hard and long about the 'Phys. Soc.' to consider whether they can equally well and as rapidly obtain elswhere all the information there displayed, albeit incomplete, and as science and as novelty spread over so wide a range of quality. It has helped to keep my picture of the development of the physical sciences on the move over the years since the war, and by crushing most of the active centres' contributions into not very comfortable surroundings, offers opportunities for some brief appraisals of trends and relative progress in different quarters. Such appraisals on incomplete data are of only partial

Fig. 2 (left) Laboratory experimental model of a predictor that responds to instantaneous input
Fig. 3 (below) Electron spin resonance spectrometer

value but, unless one has supernatural powers and prerogatives, it is difficult to envisage how more sound indications of very recent work can be collected in the course of a working day.

Control and prediction

There was little attention to automatic control as such. Mr G. G. Gouriet, of Wayne Kerr Laboratories Ltd, is a new name in this field, a transplantation from telecommunications research in the B.B.C., and as sometimes happens when fresh minds are brought to bear his results are interesting, even unconventional. His company had two exhibits concerned with control technique, the transfer function computer (Fig. 1) and a laboratory experimental model of a predictor (Fig. 2). The former device is for the measurement of transfer functions of elements over the frequency range 0·01 c/s to 500 c/s by feeding back the response of the element under measurement to the computer. The transfer functions may have terms up to the fourth order in the numerator and the sixth order in the denominator, a setting knob divided to three significant figures being provided to adjust the value of the coefficient of each term. The computer has a cathode ray tube balance indicator to compare the response of the element with that of the instrument, and this shows when the transfer-function with coefficients set by the knob corresponds in gain and phase to that of the element being measured. The values of the coefficients are then read from the knobs in the corresponding positions in the terms of the transfer function, so completing the analysis.

The predictor is based on another view by Mr Gouriet of his paper* published in 1957. As as example in that paper he took the transfer function:

$$\frac{1}{f(p)} = \frac{1}{1 + p\tau_1 + p^2\tau_2 + p^3\tau_3 + p^4\tau_4} \quad \ldots (13)$$

and established by his preceding analysis the values that the coefficients of p must have for the group delay to be constant in the maximally flat sense. Substituting $j\omega$ for p he eventually obtained his equation 17 on substitution in his equation 13 so that

$$f(p) = 1 + p/\omega_0 + K(p/\omega_0)^2 + (K - \tfrac{1}{3})(p/\omega_0)^3 + \tfrac{1}{3}(K - {}^3/_5)(p/\omega_0)^4 \ldots (17)$$

Here K is now an arbitrary constant, and he plotted normalized group delay in Fig. 1 of his paper, for various values of K, and showed it to be maximally flat for $K = 3/7$.

Subsequently he saw that this maximally flat condition was that required for an accurate predicting device. The demonstration exhibited (Fig. 2) is the result, and it consisted of a random function generator, limited in band-width to 0·1 c/s from d.c., connected to a fourth-order system. The generator input to the system was displayed on a pen recorder. The system computed the predicted behaviour three seconds in advance of the input and from its present instantaneous value, the prediction being displayed on a pen recorder similar to the input. Good agreement in form between input and output was seen. Mr Gouriet claimed that his predictor differed from other types because they made use of statistical weighting of previous inputs, whereas his was responsive only to the instantaneous input.

The N.P.L. had an adaptive control system on show, designed especially for experimental work in this field, and Elliott Bros (London) showed their Optimat process optimizer.

Instruments and methods

A glance at *Control* for last month gives a rough indication of the balance of interest. The properties measured by exhibits under the heading of analytical equipment were diverse, with chromatography a fairly frequent topic. Radiation spectrometry whether using wave-lengths in the visual range or otherwise, was not much in evidence, perhaps an expression of the extent to which this field has reached the state of detailed development and industrial application. There was very little mention of electron microscopy and even in those quarters (or is it that quarter?) of the Exhibition where it was for many post-war years a mainstay, one might say the sheet anchor or groyne of the stand, other tech-

*Gouriet, G. G.: 'Two Theorems Concerning Group Delay with Practical Application to Delay Correction', *Proc. I.E.E. Part C*. 105. 7. March 1958, pp 240-244.

niques in this difficult sphere of composition analysis were on view, notably mass spectrometry and electron spin resonance spectrometry. Hilger & Watts' version of the latter is illustrated in Fig. 3. E.S.R. is not a substitute for the earlier-developed technique of nuclear magnetic resonance but is complementary to it, and will permit some more of the unknown, particularly in complicated or hitherto intractable problems in industrial analysis, to be illuminated, measured and brought under control.

The palm in the analytical equipment exhibits probably goes to the Research Laboratory for Archaeology and the History of Art in the University of Oxford. It was the largest University stand I think I have seen in this Exhibition for a long time, and it was resplendent with rack upon rack of very sophisticated equipment. It included a high-vacuum automatic X-ray fluorescent spectrometer to permit large specimens (pots, bronzes etc) to be chemically analysed for all elements in the periodic table down to carbon, non-destructively. There were also some magnetometers and a transistorized β-ray back-scatter meter for investigating ceramic glazes. We must be forewarned, for a degree in archaeology may become the *sine qua non* for a top job in oil refining or some other field that instrument and control engineers have felt convinced is theirs inviolate so far.

Data processing

Attention to thin-film techniques for data processing was limited but interesting, although state and commercial security limit the exposure of work in this subject and on microtechnique generally to a level well below its ultimate importance. The Royal Radar Establishment were nevertheless the most forthcoming in describing techniques employed in miniaturization, which is something of a paradox.

There was a notable absentee in the digital differential analyser. Logical units were on show from the well-known sources, and joined by W. H. Sanders with some toroidal transductors as the basis. Magnetic-amplifier devices otherwise were not much in evidence—another change from recent years. Analogue-to-digital converters and their conjugates were also little exhibited.

Mr Peter Wiggs of the Morgan Crucible Co. showed an electronic analogue of a kiln in which the temperature-time duty cycle was non-linear. Mr Wiggs' interest in this analogue was to study the economics of fuel consumption during the cycle. The analogue (Fig. 4) was a laboratory bread-board model which had served Mr Wiggs' purpose. He thought (and how I agree with him) that there should be more displays of the kind at the Exhibition.

Some measurements which have been carried out by established methods for many years have been solved by new approaches. Avo showed an idea for nuclear counting which has graced the Exhibition before. It is due to staff in the U.K. Atomic Energy Authority and had been developed to the prototype stage by the exhibitor. The count is made by circuits using transistors and 'square loop' magnetic cores, the latter being arranged in an annulus around the moving indicating system. This system consists of a magnetic compass suspended so that it rotates to the position of the core in the annulus which is in the magnetic condition to indicate the count made by the unit. Each unit counts from 0 to 9 and while the moving indicating system will not follow high counting rates, which can extend to 1 Mc/s, it will assume the final count when it has been reached. Further, when the power supply is cut off the count continues to be indicated and is not lost, as it is with electronic scalers with meter or gaseous discharge indication. A further claim for the instrument is very low power consumption at 0·25 μA/count/s at 15 V.

In quite another field of measurement, and one of the oldest, Taylor, Taylor and Hobson showed an electronic level. The spirit bubble is replaced by a pendulum whose displacement is electrically transduced and displayed on a needle indicating meter on which the value per division can be as small as two seconds of arc. Remote indication of level is available, and clearly also the device is the basis for an automatic levelling system of considerable sensitivity.

Fig. 4 Bread-board electronic analogue of a kiln with non-linear temperature-time duty cycle

The apprentices submitting work in the Craftsmanship Competition seemed to me to come from a larger number of firms than last year, which is a healthy development. Clearly we have the young men coming on who will be able to keep on making Britain's glory, which is a superbly designed, constructed and finished instrument.

Hints for next time

Next year I hope the Exhibition may be able to make a few changes. Could not some exhibits which are of the same type of instrument be grouped together instead of segregated on the exhibitors' stands with sometimes incongruous items from remote fields alongside? And, please, may we have the Handbook printed on lower-weight paper, and more consideration given to easy reference in it?

What's wrong with d.p. machinery

Last month's soul-searching at the I.Mech.E. revealed uncertainties about philosophy, costs, competence, research and technique

THE IDEA OF HOLDING THIS MEETING,* EXPLAINED THE chairman of the opening session, was sparked off by a feeling that the mechanical side of data processing was not completely satisfactory. The chairman (A. W. J. Chisholm, Royal Technical College, Salford) went on to say that reliability would demand more and more attention as manufacture came under automatic control.

H. A. V. Bulleid (British Nylon Spinners) started the first session going by trying to define 'reliability'. His definition was 'percentage availability, for use *when required*, within specified accuracy tolerances'. 'Availability' meant the time specified by the engineer as 'available', and excluded scheduled maintenance—*and* emergency maintenance. There was a finite limit to 'accuracy', and it was surely better to face that and encourage the user to monitor more. This was more valuable than striving for perfect accuracy.

Following Bulleid to the rostrum, J. W. Freebody (Treasury) said it was often overlooked that the mechanical content of automatic d.p. systems was very considerable, and that it was useless to have a computer which was 100% reliable if the mechanical bodies around it were not of the same order of reliability. About ten years ago it was a matter of amazement that an electronic computer should work at all. Nowadays many of them worked extremely well, and there had been considerable advances on the electronic side. Something had to be done to make the mechanical side measure up to the electronic. One could change a capacitor or whatever it might be in hours or days, and modification was much easier than with mechanical equipment. He felt that there were too many attachments, afterthoughts. One obviously could not foresee everything, but market research should be done and the design should be an integrated whole. In the quest for reliability one had to consider first cost, but this was not the only cost. The important thing was annual charge. 'If customers, need education to realize this', added Freebody, 'then they should be educated'.

H. McG. Ross (Ferranti) said that isolated errors were extremely insidious, and stated bluntly that these had to be reduced by a factor of ten or a hundred. How could such improvements be obtained? Management should consider whether it was possible in the mechanical engineering business to copy from the electronic industry, where great advances had been made in a relatively short time. Electronic parts were being designed by teams led by men of Ph.D. standing. Were there comparable conditions in mechanical engineering? There was movement in the electronic industry, so that people gained wider experience. In many teams there was an atmosphere which allowed mistakes without holding them against men too much. If people were to have new ideas and try them, it was no use holding it against a chap if nine out of ten of his ideas were bad. 'Why not let the price of this equipment go up?' asked Ross. With the extra money they could develop new techniques to achieve reliability. The actual proportion of cost in a complete data processing installation of the purely mechanical part was seldom more than 5%. The greatest hope of progress lay in time-sharing and electronic operation. Electronic engineers had got fed up with waiting for the mechanical engineer to make the grade, so they had devised the time-sharing technique whereby the computer could keep many mechanisms going simultaneously. All the decoding and stopping and starting and so forth, and accurate timing, should in future be electronic, leaving the work for the mechanical engineer so much simpler.

A B. Barnes (Leo Computers) asked whether there was need for stand-by equipment. If the break-down rate could be reduced then the cost of stand-bys (a printer might be 10% of the cost of a complete installation) could possibly be avoided. The repair time, the time to get equipment going again, had to be low, at about the level of fifteen minutes, and should not depend on the presence of a brilliant engineer. The equipment often knew more about what was wrong than the person trying to deal with it, and the idea of equipment 'talk-

* Informal Discussion on the Reliability of Mechanical Engineering Parts of Data Processing Systems, Institution of Mechanical Engineers, January 5, 1960. Our report of the meeting is necessarily very much abridged. A full report will be available from the Institution at £1 per copy.

ing' to the person mending it was quite feasible. Replacement struck one as better than mending, but it was vital that a replacement module should not require lengthy adjustment with the rest of the equipment.

The chairman opened the meeting for general discussion, drawing attention to the comparison that had been made between the mechanical and electronic contributions. The first speaker (Bennett, A.E.I.) suggested in explanation that electronic equipment tended to be an assembly of special components (like resistors, capacitors, transistors) made by experienced manufacturers, while the mechanical engineer tended to make everything himself. The intellectual quality of electronic and mechanical designers was about equal. He thought that the cost of a typical d.p. installation would be roughly equally shared between the mechanical and electronic parts, and a fourfold increase, or even a doubling, of the cost of the mechanical portion would be a serious handicap.

Figures given by a later speaker (Nichols, of Boot's) showed that the number of electronic failures in seven months' operation of his firm's computer at Nottingham had been entirely comparable with the number of mechanical failures, but the majority of electronic faults could be removed before they caused trouble. Mechanical faults halted programs in a ratio of 10 : 1 in terms of lost machine time. Telephone equipment, he added, worked 24 hours a day, with highly unreliable components, and managed it because there was no stop for maintenance. Redundancy was essential.

Quality of mechanical engineers

After the chairman had drawn the discussion back to the quality of mechanical engineers, T. N. Gillbe (Borough Polytechnic) traced the trouble to the lack of small-mechanism-design training. J. R. Halsey (I.B.M.) found the fault in a national attitude. He spoke of his experience with switches that would carry 10^9 operations before breaking down—and of his bitter experience with a car gear-box which had broken down after about 10^4 operations. A. H. Cooper (E.M.I.) then eased the strain a little by saying that he could speak with considerable affection, and almost reverence, of some mechanical engineers in this country, but so many had been put on to making gyros for guided weapons rather than high-speed printers. H. Tipton (I.C.I.) also spoke up for the mechanical engineer. As a physicist, he thought that the electronic engineer had an easier job than the mechanical because electronic systems obeyed equations more closely and could be tested in component parts by instruments like voltmeters. The counter-attack was carried on by another speaker (Jones, Data Recording Instrument Co.) who queried very strongly whether a Ph.D. or any other degree conferred a flair for design. The electronic engineer worked more on paper than the mechanical man, because he knew he could get his standard components within certain tolerances, but one needed a lot of practical experience to work with metal and hardware. J. W. Nichols (U.K.A.E.A.) then pointed out that the electronic engineer used feedback to get round the difficulties of 'standard' components which were *not* standard. Could this be applied in the mechanical field?

L. Landon Goodman (E.D.A.) saw a glorious future for the mechanical engineer. In the United States it was being said that 'if it works it is obsolete', so mechanical engineers were not obsolete.

Computer design and manufacture

The chair was taken by L. Landon Goodman for the second session. W. A. J. Davie (Elliott Bros) opened by saying that electrical failure was always preceded by a mechanical failure of some sort. The most important factors calling for ingenuity in design were temperature stressing, vibration, dirt, and human usage.

A. H. Cooper (E.M.I.) looked back ten years to computers that were essentially a lot of wireless sets put together—needlessly expensive, heavy and strong. Today they had moved very largely towards printed cards, though these had had a troublesome history. Cards did not like being bent, and another source of difficulty was the use on them of components more rigid than the cards themselves. Components were soldered to the wiring, in the old days with soldering irons and considerable risks. Nowadays the number of dry joints had come right down. His company had found no substitute for prolonged vibration testing to discover them.

Printed cards had to be interconnected, and the standard connexion was the plug and socket. Any electronic development engineer would tell them just how lousy plugs and sockets were, but men in the field found them among the least troublesome components. This was because the behaviour of a plug and socket depended critically on the discipline applied in assembly. He liked wrapped connexions very much as an alternative to soldering plugs and sockets, but not in computers. They were large compared with soldered joints, but a bigger disadvantage was that a joint could not be unwrapped without risk of a short circuit. With ordinary electrical equipment one should probably switch off while doing this, but one could not switch off a computer while it was being maintained because one would probably be running a program. An alarming number of computers suffered from 'morning sickness' when switched on. It was a very good thing to keep them running. People talked with hushed voices about 24-hour-a-day working, but that was just what a computer loved.

Taking over the rostrum from Cooper, J. R. Halsey (I.B.M.) explained how the environment of a computer affected its serviceability and had therefore to be controlled. Temperature, humidity, dust and vibration were the factors. It had been said some time ago that transistorized computers would cure heat-disposal troubles, but they had made them worse. Though watts per circuit had gone down, circuits per unit volume had gone up, and one ended up with the same watts per unit volume and a very much more restricted passage for much greater quantities of air (transistors were more

sensitive to temperature rise than valves). A major technical break-through was required to get this problem under control. There was a tendency to change from air to oil as a heat transporter. Another way was to provide good conducting paths through the structure.

Opening the meeting to general discussion, the chairman asked whether it was time to re-think the whole design of this equipment. Was it right to sell a unit in its nice pressed-steel case and think this the be-all and end-all? Such units were not easy to service. Did the suppliers often make sure that the customer had a room prepared with the proper conditions and plant adjacent, with electronic equipment put around on racks? F. J. M. Laver (G.P.O.) responded immediately to the chairman's question because, he said, this subject was his hobby horse. He thought the trend towards ever smaller computers and ever glossier cabinets was a very bad one. Volume and floor area were not very significant to the user—provided he could separate the heat-producing from the electronic parts (in not many ships was the engine carried on the bridge).

A. Bennett (A.E.I.) questioned whether heat dissipation actually increased in the transistor machine. After all, a transistor did dissipate much less power than a valve, and components associated with transistors could be smaller, themselves dissipating this power. His company had found substantial savings in space and cooling required. J. R. Halsey replied by referring to a customer who had changed his computer every eighteen months, each time for one with eight times the previous capacity. This customer had now had four successive computers, all of which had fitted into the same room, required the same power, and pushed out the same amount of heat.

Poor research effort

A. W. J. Chisholm (Royal Technical College, Salford) commented that soldered or wrapped joints and so on were obviously of the essence of reliability over quite a big range of this equipment. Could anyone tell him how much basic research had been done? He had (in about 1953) seen what looked like some very fundamental academic research on wrapped joints at the Bell Telephone Laboratory (where there were some 6000 researchers)—a good Ph.D. topic, from the look of it. What comparable work had there been in this country? W. A. J. Davie (Elliott Bros) answered that his firm had conducted fairly strong investigation into flow and dip soldering: not on the Bell scale, of course: probably three people were looking at it for about six months. A. H. Cooper confirmed that nothing like the Bell research was going on in this country, but, thank God, Bell did publish.

Peripheral equipment

G. H. Townend (Guest Keen & Nettlefold) chaired the third and final session. F. J. M. Laver (G.P.O.) opened by saying that many electronic engineers' attitude to peripheral equipment was rather like their attitude to drains: both were unfortunate necessities, both were eagerly ignored while they worked, and both were supremely offensive when they went wrong. This situation arose partly from the patronizing attitude permitted themselves by most practitioners of new techniques, and partly from the continuing fragmentation of engineering. A deliberate effort was needed to co-ordinate electronic, electrical and mechanical contributions.

P. W. Pearson (Creed) said that although complaints of unreliability were completely justified in the early days, machines were now available to give long periods of trouble-free service. It would be interesting to ask users what proportion of their complaints applied to current equipment. L. Knight (I.C.T.) supported the defence. The detailed records of his company's service engineers showed the reliability of peripheral equipment to be roughly the same as that of the central electronic equipment. One might well ask why the electronic box was not very much *more* reliable than the electromechanical box, having no moving parts to wear themselves out. Reliability prediction was more difficult with electromechanical than with electronic equipment because of the more complicated interconnexion and interaction between unique parts.

Responsibilities and remedies

The first speaker in the general discussion, J. Kason (E.M.I.) backed up Knight's equal apportionment of blame, but A. Russell (N.E.L.) said he had found 85% electrical and 15% mechanical faults in a digital machine. I. V. Idelson (Mullard) thought that perhaps these ratios did not mean much; but, he emphasized, users found mechanical faults a particular nuisance. They would like to have a way of knowing whether their mechanical equipment was in order or getting near the edge of its adjustment. It might be possible to provide timing contacts and so forth, and points for oscilloscopes, to give rather quicker indications than one got at the moment. R. D. Lacy (Associated Automation) denied that it was difficult to detect when a mechanism was going to lead to trouble during the next day's operation, although it *was* difficult to judge whether there would be a catastrophic failure. All readers could be set up easily with the aid of an oscilloscope. It was quite impossible to check this kind of equipment by means of standard mechanical adjustments or preset limits, and it was essential to test it in the way that it was eventually to be used.

H. McG. Ross (Ferranti) advocated 'worst-case' design, assuming that every component in a system simultaneously reached worst tolerance. This method had helped his company make the grade in the electronic field. Another thing which had helped them to make the grade was negative feedback.

'It would be quite impossible for me in any way to attempt to summarize what has been said', concluded the chairman at the end of the day, but he thought they had had a very interesting discussion. Most of the departing delegates agreed with him.

Although the attitude of some is coloured by their apparently greater faith in program control, German machine-tool builders have made serious approaches to numerical control

GERMAN DEVELOPMENTS IN NUMERICAL CONTROL

by **R. C. BREWER**
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ONE OF THE MOST CONSPICUOUS FEATURES OF THE FIRST decade of numerically-controlled machine tools was the almost complete absence of any interest on the part of European machine-tool builders. Also, early surveys (*1*, *2*) showed only one control system of continental origin namely that of the Berliner Maschinenbau A.G. (formerly L. Schwartzkopf); this was an extremely simple system, with no feedback in the strict sense of the word, so that the term 'numerical control system' could only be applied to it in virtue of its method of handling the command information.

With a substantial part of its machine-tool industry devoted to the general-purpose type of machine tool, Germany's neglect of numerical control may seem rather surprising at first sight. Upon reflexion, however, one can see several factors which must have influenced German manufacturers of both machine tools and control systems. Firstly, the potential market must have appeared very small six or seven years ago, and, with several British and American companies already active in this field, a policy of restraint was possibly prudent. Moreover, the costs of research and development were known to be very high, even for positional control systems, so that the possibility of recovering capital expenditure in a reasonable time would have seemed remote. This contention would seem to have been borne out by the subsequent experience of many companies who entered the numerical control field with more enthusiasm than forethought.

A second factor was the attitude of the German machine-tool industry to automatic operation. Until recently, German machine-tool builders thought almost entirely in terms of inexpensive control systems which did no more than ensure (i) that the machining operations were performed in the correct sequence and (ii) that the moving elements (such as tool-holders) were stopped in the correct positions at the end of each operation. The former function was achieved by the use of some form of stepping switch, and frequently, when the machine tool had a hexagon turret, the indexing of this turret was used instead of an external stepping mechanism. The latter function was performed by 'setting-dogs' or trips in special guide-ways provided on the machine-tool bed and table.

In this type of program control the program for the sequence of operations is set up on a plug board or matrix array of switches. By contrast with the situation found in numerical control, a recent survey of program-controlled machine tools (*3*) showed a high proportion of German manufacture. For certain highly specialized machine-tools, such as gear-cutting machines, program-control offers almost as much as numerical control at a considerably lower price. For general-purpose machine tools, however, program control imposes the limitation that the table (or carriage) can only move along the natural axis of the machine since, between the beginning and end of a movement, the table is subject to no feedback control. In spite of this limitation there is a not inconsiderable field of application for program control, and the German machine-tool makers obviously relied more on it than on numerical control.

Awakening to numerical control

It has also been suggested that, ten years ago, the German electronics industry was not in a state to cope effectively with the research and development needed for numerical control. Recently, however, there has been a considerable increase in the interest displayed by German machine-tool builders in numerical control. About a dozen companies are offering machine tools equipped with numerical control, and details of these are summarized in the accompanying table. Not every company is publicizing numerical control with the same enthusiasm as it gave to program control, but evidently there is an awakening feeling in Germany that numerical control can no longer be ignored.

It will be seen from the table that three control systems are British or American and the remainder German. The balance between the numbers of positional and continuous-contour systems is comparable to the

distribution here and in the U.S.A., although in fact only one of the two continuous-contour systems is German, the other being the well-known E.M.I. analogue system. Of the machines with positional control the most popular is the drilling machine, although the most interesting feature is the presence of two vertical milling machines in the list. Clearly, this type of machine really requires a continuous-contour control system, and the use of positional control limits the movement in the same ways as it is restricted in the program-controlled machine. In these circumstances, numerical control is applicable only to the same components as program control, and its advantage over program control lies solely in the easier programming and setting-up of the machine. To this extent, it would appear that at least a section of the German machine-tool industry, still regards numerical control not as an approach more advanced and sophisticated in form than program control, but as an alternative to it, to be used when components have to be produced in several small batches over a period of time rather than in one large batch at the outset.

Standard storage media

A glance at the table will show that German control-system manufacturers have realized one advantage from not being pioneers, namely a much greater degree of standardization with regard to permanent storage media. All control systems with a serious storage medium employ punched tape in preference to punched cards, and the only tapes which are not of the five-channel type are those for the two American control systems. The Germans have rejected the eight-channel tape (which is now the American standard), probably for the following reasons:

a Five-channel tape is the input for the main German computers (Siemens 2002, Zuse Z22 etc.).

b The international telegraph code is five-channel.

c The use of five-channel tape is wide-spread in the U.K. and U.S.S.R. It will be noted that, in half of the systems where a permanent storage medium is provided, the international telegraph code is used. In the remaining systems a special code or 5/3 code (*4,5*) is used.

Each of the first three items in the table is a plain drilling machine equipped with a simple co-ordinate positioning system. No permanent storage medium is provided in the true sense of the word, although the setting of the Berliner Maschinenbau system may be facilitated by the use of a punched card which can be laid over the plug-board. The advantage of such punched-card over manual setting of decade switches may be rather questionable, but the system has been described in the table as having permanent storage facilities.

The analogue system of the Collet and Engelhard machine employs synchros for the transducers—this form of transducer, in fact, is common to all the analogue systems of German origin. The Scharmann and Berliner Maschinenbau systems are digital, the former using digitizing disks for the transducer, while the latter employs a more complicated measuring system. In essentials, the distance through which the table has to move (along a given axis) is built from a series of standard gauges placed end to end. The gauges are arranged in sets corresponding to the digits for the tenths, units, tens etc. of millimetres, each set being accommodated around the periphery of a drum which is indexed from the numerical information set on the plug board. Thus, the table is under effective control only in the final deceleration which follows the closing of the limit switch.

The remaining positional control systems have permanent storage on either five- or eight-channel punched tape. With such systems, it is of considerable advantage to have some buffer storage between the tape reader and the control system, and the data in the table show that transistor and relay stores are most popular.

In addition, the analogue systems for the Karl Hüller and Fritz Werner machines have digital-analogue converters coupling the buffer store to the control system. The Hüller drilling machine is equipped with the synchro system of the American General Electric Company of Waynesboro, Va. This has been described adequately elsewhere (*1*). Basically, the numerical information from the tape reader is fed to a circuit of tapped transformers which provide an analogue voltage corresponding to the relevant co-ordinate of the next table position. This voltage is compared with the output from the synchros geared to the leadscrew, the table being driven by a d.c. motor until there is coincidence.

The Fritz Werner milling machine, controlled by the Brown Boveri positioning system, was first shown at last autumn's Hanover Exhibition. This was a special machine with only one feed-motor, so that the co-ordinate movements had to be executed consecutively, but the production models will be equipped for simultaneous movement along the axes. In spite of this, the system is only a positional control system, and its use for continuous milling is only possible by restricting its mode of operation to that of a program-controlled milling machine (as discussed earlier).

The Heller and Kolb drilling machines require only two-axis control and employ simple optical gratings for the feedback information. The pulses from the photo-diode, which views each grating, are fed to a counting circuit and subtracted from the digits set by the command information. As the residue approaches zero, the table is decelerated and moves towards its final position at an inching speed. It is of interest to note that the control system used with the Kolb machine was developed by the technische Hochschule, Aachen; this is the German counterpart of the Massachusetts Institute of Technology, where much of the original work on numerical control was carried out.

The Bohle and Burkhardt und Weber machines are controlled by systems using special forms of digitizing disk. The S.E.L. system on the Bohle milling machine employs an optical disk and generates the pulse train photo-electrically. The Burkhardt & Weber machine is a special-purpose three-axis machine. The transducer

	MACHINE TOOL MANUFACTURER	TYPE OF MACHINE TOOL	CONTROL SYSTEM MANUFACTURER (IF DIFFERENT FROM COLUMN 1)	NO. OF AXES	PERMANENT STORAGE MEDIUM: TAPE (T) OR CARDS (C)	PERMANENT STORAGE MEDIUM: NO. OF CHANNELS	CODE	BUFFER STORAGE	ANALOGUE OR DIGITAL	TRANSDUCER	DRIVE
†	COLLET & ENGELHARD A.G.	Drilling	S.S.W. (Erlangen)	2	—	—	—	—	A	Synchros	D.C. motor
†	SCHARMANN & CO. G.m.b.H.	Drilling		2	—	—	—	—	D	Digitizing disk	D.C. motor
†	BERLINER MASCHINENBAU A.G.	Drilling		2	C	—	—	Relays	D	Measuring bars	Hydraulic
†	GEBR. HELLER G.m.b.H.	Drilling/milling		2	T	5	I.T.	Transistors	D	Optical grating	Hydraulic
†	HERMANN KOLB G.m.b.H.	Radial drilling	Technische Hochschule, Aachen	2	T	5	5/3	Transistors	D	Optical grating	3Ø motor
†	KARL HÜLLER G.m.b.H.	Turret drilling	American G.E. Company	2	T	8	Special	Relays	A	Synchros	D.C. motor
†	FRITZ WERNER A.G.	Vertical milling	Brown Boveri	3	T	5	5/3	Relays	A	Synchros	3Ø motor
†	REINHARD BOHLE K.G.	Vertical milling	S.E.L. (Pforzheim)	3	T	5	I.T.	Relays	D	Digitizing disk	3Ø motor
	BURKHARDT & WEBER K.G.	Special-purpose machine	Hughes Aircraft Co. (Los Angeles)	3	T	8	Special	Dekatron tubes	D	Digitizing disk	Hydraulic
*	DROOP & REIN A.G.	Milling	E.M.I.	2½	T	5	Binary-coded decimal	Relays	A	Synchros and Inductosyn	D.C. motor
*	H. A. WALDRICH G.m.b.H.	Roll-turning lathe	A.E.G. (Berlin)	2	T	5	I.T.	Transistors	A	Synchros	D.C. motor

* Continuous contour control. † Positional control. I.T.—International Telegraph Code

of its control system generates pulses by an alternation of magnetic and non-magnetic sectors, and sensing is electro-magnetic. As with the optical grating systems, the feedback pulses are fed into an electronic counting circuit for comparison with the number of commanded pulses.

Continuous-contour control

Both of the continuous-contour control systems are analogue, but they differ with regard to the stage at which the digital-analogue conversion is effected. The E.M.I. system, which is well known in this country, converts to analogue form at an early stage and performs a parabolic interpolation on the analogue voltages which represent the major and minor points defining each span. The A.E.G. system, on the other hand, delays the conversion to analogue form until after the interpolation; this somewhat reduces the amount of sheer calculation in determining co-ordinates, since it offers the flexibility associated with digital interpolation. Here, there must always be a compromise between a simple interpolator which demands a large number of co-ordinates and a highly complex interpolator which will perform satisfactorily with the barest information about any mathematically defined curve. The Allgemeine Elektrizitäts-Gesellschaft decided to follow a middle path; interpolation is effected for straight lines on a basis of the final point only, and, for circular arcs, with only the final point and the centre of curvature—all other curves must be defined by sufficient points to avoid ambiguity.

The numerical and functional command information, in the A.E.G. system, is encoded on five-channel tape according to the standard telegraph code, co-ordinates being expressed in hundredths of a millimetre (say, 0·0004 in). Before interpolation, the co-ordinates are converted from decimal to binary form, the capacity being twenty binary digits. The interpolation section is followed by a system of tapped transformers which function as a digital-analogue converter (*6*).

Synchros coupled to the leadscrew are used as transducers, and pitch errors in the leadscrew are compensated so that there is no need to allow for them in the programming stage. The comparator is, in effect, a phase-sensitive bridge.

One of the machines for which the Droop and Rein company is best known, is its profile milling machine. The type of work for which this machine is used is, in general, well-suited to numerical control, and it is not surprising that the company decided to employ some form of continuous-contour control. This system used is the E.M.I. parabolic-interpolating system which has been adequately described elsewhere (*1*). It will suffice to say that the 2½ D version is used, i.e. there is continuous control in two dimensions for some discrete value of the third dimension. This is quite satisfactory for most profiling machines, since the surface is invariably generated as a series of curves in closely-spaced parallel planes. This is, in fact, a quite logical way of generating a surface with a tool which gives virtually point contact; indeed a fully three-dimensional system is probably only of use when some portion of the surface is more easily generated in planes perpendicular to those used for the remainder of the surface.

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The computer needed for control work is different from the general run of machines. It is important that the design of a controlling computer should reflect its purpose

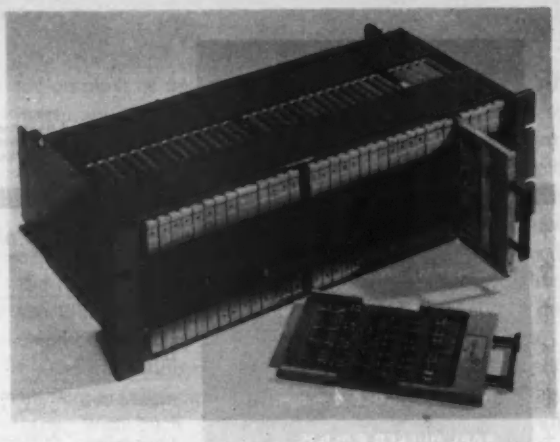


Fig. 1 An instance of packaged construction—a box of 36 printed-circuit packages. The computer is assembled from a number of boxes like this

Computers in process control

by **M. B. WOOD**
Ferranti Ltd

GENERAL-PURPOSE DIGITAL COMPUTERS WERE USED FOR the early applications in the process control field because the machines were readily available. Before this, analogue computer systems had been used for on-line computer control, and both types have their own advantages. One disadvantage of digital computers at that time was their relatively low speed, but for military applications, such as early-warning radar systems, fast digital computers were necessary. Consequently computing speed and storage capacity were developed, until today there are machines suitable for the largest control applications which occur in industry.

Analogue computers are often cheaper for small control problems, but digital systems are justifiable for large and complex situations, both on economic grounds and because of their relative insensitivity to noise. The corresponding limitations of a digital computer is rounding-off error, but this can be reduced to acceptable limits by simply extending the word-lengths used for the computations.

Although general-purpose machines have been used for process control, the special requirements of this field will result in a new generation of computers designed specially for the job.

Among the special features needed for process control are the following:

- **a** Extremely high standards of reliability
- **b** Facilities for accepting information from many different channels
- **c** Adequate computation speed
- **d** Internal time-monitoring facilities, to permit the computer to relate its operations to the external system and the process
- **e** Simplicity and low cost
- **f** Sound mechanical and electrical design, since the computer may often be situated in an unfavourable environment.

These requirements, and the ways in which the computer can fulfil them, are discussed below.

Reliability

This is one of the most important features of a successful process control computer; certainly it is the one most discussed by both potential users and equipment designers. System reliability, which is the aim here, has been defined as the probability that the system will continue to perform its required function under specified conditions for a given operating time. Whilst this is a useful general definition, the problems on a process plant are quite different from those which exist in an off-line installation. This is particularly true in the continuous process industries, where the plant will normally be operating 24 hours a day and seven days a week for months at a stretch. No company is likely to incorporate a computer into the control system for such a plant unless they are convinced beforehand that the system will continue to operate without significant break-down for many months, or even years.

The reliability problem is complicated by the fact that the computer is a part of a complex system which must be reliable when considered in its entirety. This implies that the input and output devices must also be reliable. However, input and output equipment will be considered later in this article.

The computing unit itself can be made extremely reliable, particularly if solid-state devices are used exclusively. One prototype machine in this country, using no valves whatever, has operated continuously without fault for a period of three months, during which no maintenance work of any kind was carried out. Other examples are an American machine with 700 transis-

tors, which operated for two months in 1958 with only one fault, and the Daystrom computer installed in July 1958 at Sterlington Power Station for the Louisiana Power and Light Company, which operated continuously for the six months July to December 1959 for 99·7% of the total time. Whilst this is a very high figure it still implies that the system was out of operation for some ten hours during the six-month trial. The complete system contains 4000 transistors and 7500 diodes. This kind of performance can be achieved by conservative circuit design and de-rating of components. Later machines, in which even better semiconductor devices can be used, should improve upon these figures.

In the event of a fault the time taken to repair is important, and therefore packaged construction should be employed, since reliable printed-circuit connectors are now available. One particular type, with gold-plated contacts, has been tested for wear and deterioration; after 4000 insertions and withdrawals there was no sign of damage. Packaged construction using printed-circuit techniques should reduce the cost of the machine, since the individual units can be mass-produced if sufficient numbers of machines are built. At least one general-purpose computer produced in Britain has printed-circuit wiring for the frame of the machine. The reduces the time taken for checking and commissioning, thus lowering the cost of production, because once the printed circuit is correct, the frame wiring of each machine must be correct.

Mechanical design is as important as electrical design, because the environment on a plant is unfavourable when compared with that normally associated with computers. Dust-sealed cabinets with adequate provision for cooling are probably well worth the slight additional cost.

One precaution which may be taken is to run the computer for several hundred hours before commissioning the control system, to allow for the initial burning-in characteristics of many components.

Preventive maintenance may well be unacceptable on computers controlling continuous processes, and some other approach must be employed to check the machine. Whenever possible, failures should be detected before they can affect the process, and when this is impossible the effect of failure must be minimized. Much can be done to this end in the design of the program.

One approach is to check the reasonableness of the results. Here, a maximum increment in the new computed value is specified. If this should be exceeded, then the calculation is repeated before applying the new demanded value. A different way of achieving a similar object is to allow only small increments in the control outputs, so that the effect of a random disturbance will be reset on the next computation cycle. This method is smoother in operation than the first one, which may be an advantage for some purposes.

Test computations can also be incorporated in the normal program to detect malfunctioning of the computer. A known calculation is performed on known data, the result being compared with the predetermined answer.

When there is a catastrophic failure, such as loss of power supply, control can be automatically transferred to stand-by equipment.

The computer can also check some of the instrumentation, and even the plant itself, giving warning of impending failures or suspicious conditions. The program should be arranged to reject unreasonable input information and raise an alarm. This need not hold up the control program, since specified alternative information can be provided for use until the fault is corrected.

Storage requirements

The storage requirements of a computer intended for process control are significantly different from those common in other applications. Working storage, data storage, and program storage are among the most important. In a control computer the program is normally fixed for long periods, although small changes may be necessary. Many of the data are also fixed for a particular application by the parameters of the plant and process. This is quite different from the situation in a general-purpose machine, where the program is changed for each new piece of work. For this reason, semi-permanent storage has certain advantages. If some form of peg-board is used for program storage, there is no possibility of the program being accidently changed. Where magnetic storage on cores or drums is used, accidental change can sometimes occur if there is an electrical disturbance. The peg-board may be likened to the wired-in micro-programs used in many large computers, but has the advantage that its contents can, if necessary, be changed at will without altering the physical wiring of the machine.

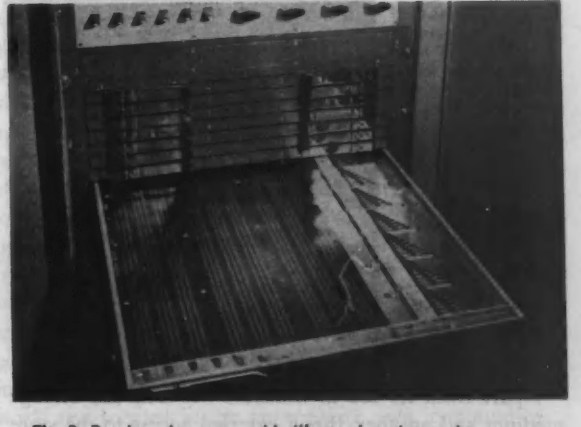


Fig. 2 Peg-board storage: this illustration shows the program storage. Orders are pegged across the boards, each of which holds 64 orders

The storage capacity normally required to hold the data for computations can be drastically reduced, because so many of the data are derived in real time from the process. Immediate computation on this data, followed by output action to control the process, elimin-

ates much of the storage which would be used in a corresponding general-purpose computation.

For these reasons a relatively large immediate-access store is usually sufficient for providing working space and temporary storage, since all constant data can be kept in the semi-permanent (peg-board) store. For many purposes a core store of about a thousand words is adequate.

These two stores can, if necessary, be supplemented by magnetic drums or magnetic tape. Magnetic tape is useful if the present history of the plant is to serve as a basis for future control action, or where the information available within the control computer is to be analysed by another computer.

Parity checking of the storage of a computer is now almost standard practice, and would naturally be included in any machine designed for control. The procedure which should be followed when parity failure is detected must be devised specially for each application.

One additional feature which can be used with the immediate-access working store is to allow direct access to this store from external equipment, both for reading and writing of information. This can be extremely useful, since transfers from other forms of storage can be effected when the computer program is not actually using the store. This avoids wasting both program time and program storage for routine transfer operations. The particular logical arrangements used will be determined by the features of the computer and the type of storage used.

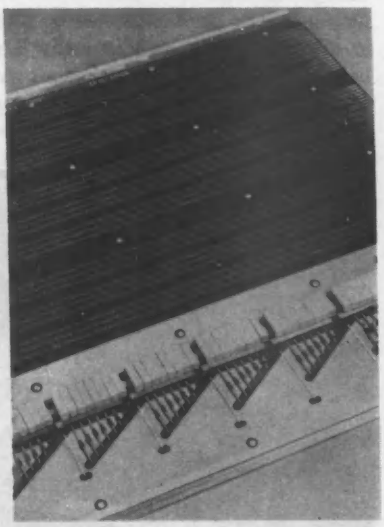


Fig. 3 Peg-board storage: a detail of the tray. The individual drive transformers are shown in blocks of eight, and select printed-circuit loops on the lower side of the board

Apart from its use in transfers between one storage medium and another, direct external access to the store can be an input-output facility and connect a number of computers to form one complex system.

Input and output facilities

On a general-purpose computer only a few input and output devices are used, whereas on a plant the instrumentation may supply data from hundreds or even thousands of different sources. For this reason the order code and logical arrangement of a process computer must include provision for selection between such numbers of inputs and outputs.

The inputs can be divided into analogue and digital signals. The analogue signals are generated by normal process instruments to represent physical quantities such as temperature, pressure, flow, etc., whilst the digital signals are derived (from limit or pressure switches for example) and yield yes/no, or binary information about the state of some part of the plant or process. This might be whether or not a particular valve is shut, or whether a temperature or pressure has reached a preset value. Digital information can also be generated by digitizers, counters and other devices.

Analogue signals must be converted into digital form before they are intelligible to the computer, whose internal logic is normally binary. For this purpose electronic analogue-to-digital converters are used.

The order code of the computer must give means for selection of any input channel, and for conversion of the information from it into a form which is compatible with the internal logic of the computer. Some simple logging systems merely scan the inputs in a predetermined order, as distinct from selecting them. In many cases it is desirable that the system should have the capacity to select any input on demand. For instance, if an unusual value appears on one input, it may be an advantage to inspect the other related inputs rapidly and in an unusual order. Hence, the computer logic and order code should be capable of random selection and conversion of information from many hundreds of input channels.

The form of output required varies with the type of application. If the computer is merely calculating operating guides and logging the behaviour of the process, then a single printer may be used. If on the other hand the computer is actually controlling the process, either directly or by changing the set points of conventional controllers in supervisory control, a great deal more output capacity is required. A typical plant may need a hundred or more output channels, each controlling one final element in direct control—or one set point in supervisory control—of a conventional control system.

Here it should be pointed out that a digital computer can readily provide large numbers of digital outputs, but it is neither simple nor cheap to provide large numbers of continuous analogue outputs. However, digital signals can be used to control analogue equipment. For example, a valve or damper can be controlled in position by a digital signal having three states: *off*, *forward*, or *reverse*. When the computer demands that a valve shall move to a given new position, a fast digital control program can be used to set the valve to the new position, using valve position as a further input to the computer. Fig. 4 shows a typical system for controlling a pneumatic diaphragm-operated valve. The two solenoid valves *A* and *B* are normally closed. If the valve is pressure-closing in action, then, when solenoid *A*

operates, the main valve will tend to close. Conversely, solenoid *B* will cause the valve to open. The two solenoids are operated from the computer, to which valve position is sent as an input. The computer program is then arranged to compare the present valve position with the position demanded by the control equations, and actuate the solenoids in an appropriate manner.

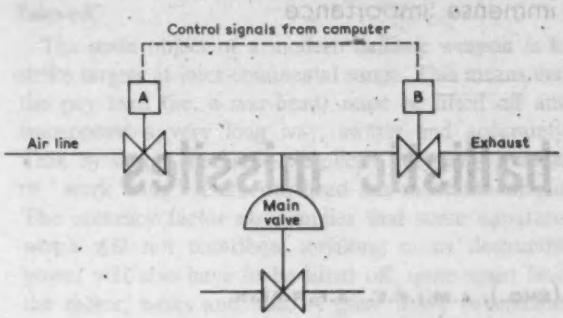


Fig. 4 Digital control of diaphragm-operated valve

For most purposes, therefore, digital control can be used. However, for some applications, analogue output signals may be essential, and for these digital-to-analogue converters can be used. These are complementary to the analogue-to-digital converters used at the input to the computer. They produce an electrical analogue signal proportional to a digital number supplied by the computer.

Speed of computation

Although most processes have inherently low-frequency characteristics, they are often complex in character. The rate at which information is available from a well instrumented plant is large, since, although the individual instruments may provide only low-frequency information, the large number of channels involved increases the band-width required from the computer. Again, the programs needed for optimization or computer logging may be extremely complex—a computer is hardly justifiable where only a few simple operations are required. Fast computers are relatively cheaper than slow ones in terms of the amount of work which they can perform in a given time. The speed of the computer should therefore be relatively high, since this allows a margin for future development of the control program. The lower limit to the speed of the machine is set by the requirement that it must operate in real time. Hence, although a particular machine may be able to solve the equations of a given control problem, it is useless unless the computation can be done in real time compatible with the time scale of the process.

Time monitoring facility

A feature of process control computers which is not encountered in general-purpose ones is the need to relate computations to time. In sampled-data systems, or in forming averages of the value of a process variable, it is usually desirable to sample the process variable at fixed intervals of time. Normally this is not easy to arrange by program because some functions, such as multiplication and division, and special subroutines, often take a variable time for completion. Thus, an internal real-time clock, which can interrupt the program at definite times, is a very desirable feature. The logic of the computer should enable the clock to interrupt the program after an interval specified by a previous part of the program. In practice this might be arranged with a counter which is filled by program with a number representing a definite time interval. The number in the register is then reduced by unity every word-time until zero is reached. At this time the interruption occurs. The program is now so arranged that the original program can be resumed after the time-dependent operation is completed. For practical purposes, therefore, the main program is interrupted at a time specified by the program some time beforehand. When the interruption occurs some special program is followed, which first stores information to permit the main program to be resumed, and then carries out some special operation. Afterwards the main program is again resumed at the point where the interruption took place. A new interruption demand can be stored in the timing counter system, to call the same or a different interruption program at some future time. This facility permits quite complicated timing procedures to be programmed by using multiple period-lengths.

In addition to this interruption timer, the computer should also have a real-time clock scaled in hours and minutes. This is needed to print data at fixed times, and for other purposes.

Conclusions

If computers are ever to gain wide acceptance for process control they must be understood by the people who have to operate them. For this reason they should be kept as simple as possible. If large systems are required it may be better to use a number of small interconnected computers rather than one enormous machine. Here packaged construction comes into its own, since the computer becomes effectively one large package. If external direct access to the store is available, then individual computers can be connected together via their stores. In this way the computers can operate as a team, which together form a complex control system. These computers need not necessarily be in one place. For instance, it would be possible to have a number of simple computers controlling a large interconnected electricity supply network, with each of the individual computers controlling a section of the network and located in the appropriate area, communicating with the others through data links.

It will be appreciated that process control requires the computer to have certain special features, which are quite simple provided they are considered in the initial design stages.

Acknowledgment

Acknowledgment is due to Ferranti Ltd for permission to publish this article.

PART 1

An introduction to a fascinating subject, this article shows the immense importance of integrated design

Controlling ballistic missiles

by **K. C. GARNER, B.SC.(ENG.), A.M.I.E.E., A.F.R.AE.S.**
College of Aeronautics, Cranfield

A PREVIOUS SERIES OF ARTICLES ON GUIDED MISSILES has provided an elementary but informative introduction to the fundamentals of guided-all-the-way missiles (*1, 2*), where a feedback loop is maintained between target and missile throughout their trajectories. Ballistic missiles are quite different, as during the final phase of their trajectory they are open-loop devices. In certain respects they are similar to artillery shells. Before ballistic missiles can be of any use, the position of their target—and their launching position, if fired from a mobile base like a submarine—must be known to a high degree of precision. The control phase of a ballistic missile is, in effect, the gun barrel which initiates a satisfactory free-flight trajectory for the war-head to follow. Another major difference between ballistic and aerodynamic missiles is that the former are temporarily space vehicles and cannot make use of aerodynamic forces to provide controlling moments for the adjustment of their trajectories. For ballistic missiles a rotatable resultant thrust is used instead. As with all problems in control engineering, as many as possible of the influential factors must be accounted for to obtain a reasonable solution.

The primary question the control engineer asks is: why cannot this missile be controlled all the way? It is only necessary to consider the enormous ranges, up to 5000 miles or more, to find the answer. To develop a feedback-data loop which is reliable, accurate, and immune to counter measures, while not impossible, may well be expensive, and almost certainly may take too long to develop to be of current value. Furthermore, a power supply of duration equal to the total flight-time would be required. However, the really great advantage of the open-loop final phase is that it is virtually impossible to find a counter measure short of destroying the war-head itself. Therefore, excepting that beyond a certain range no control is necessary, the uncontrolled trajectory must be computed with great accuracy. As in gunnery, this trajectory will be determined to a very large extent by its initial conditions. These initial conditions are, of course, the end conditions of the controlled phase, and can be considered as the control team's 'target'. Thus the control team's problem is to provide the desired initial conditions to initiate the free-flight trajectory as accurately and economically as possible, assuming the kinematics of the ballistic path to have been correctly computed to strike in the target area eventually. For any ballistic trajectory, i.e. a trajectory along which the projectile is in free flight and not influenced by aerodynamic effects, there are, at any position along it, a unique velocity and acceleration with respect to a specified reference frame. It would appear at first sight that it is a relatively simple mathematical problem to determine a suitable trajectory from the launching point to the target. This would be so if the missile could be launched at the azimuth and elevation angles and velocity as if it were indeed fired from a gun. However, this would be far from an optimum procedure for a missile, simply because the time spent in 'thick' atmosphere prolongs the aerodynamic drag, and wastes propulsion energy in kinetic heat. Thus the take-off of the rocket is at or near the vertical, in order to take the shortest route through the atmospheric impedance. Subsequently, the projectile alters course on to a tangent to a suitable free-flight trajectory. The point of tangency to any trajectory occurs at the 'all-burnt' or war-head-separation instant. From then on there is no further thrust or control. At this point of tangency, therefore, it is essential to have achieved a correct instantaneous velocity in order to generate the desired

trajectory. With a wrong velocity there will still be a point of tangency, but with a relatively useless or inefficient trajectory.

The elementary theory of the ballistic trajectory is given in an appendix to this article. Note that errors in azimuth yield very serious miss distances.

Take-off

The main object of a modern ballistic weapon is to strike targets at inter-continental range. This means that the pay load (i.e. a war-head) must be lifted off and transported a very long way, swiftly and accurately. This, by simple mechanics, implies a very large amount of 'work done' if the war-head has moderate weight. The accuracy factor also implies that some apparatus which will not contribute anything to its destructive power will also have to be lifted off, quite apart from the motor, tanks and hull. A great many calculations have been made to determine the optimum size and shape of a ballistic rocket, and are based on the fundamental mechanics equation

$$m\dot{v} = -S\dot{m}$$

where m is the mass of the rocket
v is the velocity of the rocket
S is the specific impulse.

The specific impulse is a measure of the propulsive effort and is a crucial number in any rocket design: it is fixed by the propulsion unit. The integral of the above equation is of particular interest (since it provides one of the basic control parameters, the all-burnt velocity V_o), namely

$$m_L = m_o \exp(V_o/S)$$

where m_L = launching mass
m_o = mass at cut-off.

Thus, given a particular motor, there may be a fairly well defined optimum launching mass for a single-stage rocket which is to develop a specified all-burnt velocity. This is based on consideration of the initial fuel load, the structure needed to support it, the war-head and sundry power, guidance, and control apparatus, and the rate of fuel consumption. For long-range missiles, however, the desired all-burnt velocity may well exceed the value obtainable from the single-stage rocket, so that two, or even three, stages may be necessary. This staging is based on the philosophy of discarding redundant mass as it becomes redundant. Empty fuel tanks and exhausted motors are rejected as the flight proceeds. Calculations based on these mass-ratio considerations generally yield an optimum launching mass which maximizes the all-burnt velocity, and thus the maximum operational range of the missile (*3, 4, 5*). However, the optimum generally demands an extremely flimsy structure, which is often rather shorter and of larger diameter than an aerodynamically designed vehicle of the same weight. All this leads to a vehicle shape and structure which is not at all suited to aerodynamic control. Nevertheless, this rocket needs to fly through the atmosphere for many tens of miles.

For similar reasons it is also undesirable to accelerate the missile during vertical ascent initially by more than one or two g. This pleases the propulsion people, and at the same time minimizes the effects of kinetic heating during the initial trajectory. However, certainly over most of this period, the vehicle (which is usually wingless) cannot generate much in the way of useful aerodynamic moments for stabilizing its attitude. Nevertheless, during this 'aerodynamic' phase the control system will also have to correct for any aerodynamic malalignment which may be present. Thus the rotating thrust is necessary even in the initial stages of the flight. This technique in modified form is not new, and was used in the German A4(V2) missile in the last war (*6*).

Dynamics of a rocket in space

Since the greater part of a ballistic-missile trajectory is outside the earth's aerodynamically useful atmosphere, it is no longer possible to correct the trajectory by utilizing aerodynamic lift, but there are some alternative methods which can produce the desired flight-path modifications. The primary requirement is, of course, to provide a thrust component normal to the instantaneous flight-path velocity vector. This can be achieved by using auxiliary jets fitted at right-angles to the fore-and-aft missile axis, or by changing the direction of thrust of the main motor with controllable vanes

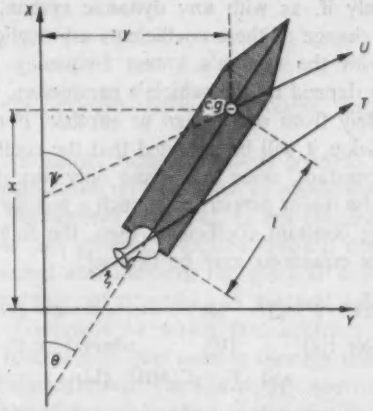


Fig. 1 Lateral dynamics of a missile in vacuo

in the motor efflux, or by swivelling the motor assembly as a whole. The last method will be used as the example in this article since it is the most simple to visualize. In all cases it is the rotation of the resultant thrust vector which matters.

Fig. 1 shows the dynamic problem stated for an angled-thrust rocket, from which the following five equations can be stated, assuming that we can for the moment ignore gravity.

$$m\ddot{x} = T\cos(\theta+\zeta) \quad (1)$$

$$m\ddot{y} = T\sin(\theta+\zeta) \quad (2)$$

$$C\ddot{\theta} = -Tl\sin\zeta \quad (3)$$

$$\dot{x} = U\cos\psi \quad (4)$$

$$\dot{y} = U\sin\psi \quad (5)$$

all with reference to an inertial co-ordinate reference

frame XOY. Eliminating x and y, and solving for $\dot{U}$ and $\dot{\psi}$ we can derive that

$$\dot{U} = (T/m)\cos(\theta - \psi + \zeta) \quad (6)$$

$$\dot{\psi} = (T/Um)\sin(\theta - \psi + \zeta) \quad (7)$$

It is apparent that these are non-linear equations, and for an accurate investigation of their behaviour a detailed study on analogue or digital computers, or both, would be necessary. At a later stage in the design this would indeed be carried out. However, it is possible to obtain much preliminary assessment of the rocket design by making various linearizing assumptions which, of course, are only valid for the artificial conditions assumed. Nevertheless, by careful choice, such initial 'guesswork' can be extremely valuable. The first condition is that all angles are small, and to linearize still further it is necessary to regard all coefficients as constant, although in reality they change with flight time. The mass of the rocket, m, and the pitching moment of inertia, C, will vary as the fuel is burnt off. Likewise, distance l will vary with fuel consumption, although only by a small amount in a liquid-fuel rocket, where the fuel tankage is arranged equally on each side of the missile's centre of gravity. The thrust, though nominally constant, is never quite so, and neither is U. Therefore the assumption that all these are constant will give a useful degree of approximation in a paper study only if, as with any dynamic system, the time rates of change of these coefficients are negligible compared with the system's lowest frequency. This will naturally depend on the vehicle's parameters, which can vary widely from one design to another. For the sake of discussion it will be assumed that the coefficients *do* remain constant, since this is the only way of demonstrating the major properties of such a missile on paper. Assuming constant coefficients then, the following approximate equations may be derived:

$$\dot{\psi} = (1/T_1)(\theta - \psi + \zeta) \quad (8) \qquad \ddot{\theta} = \zeta/T_2^2 \quad (9)$$

$$\ddot{y} = (U/T_1)(\theta + \zeta) \quad (10) \qquad \text{where } T_1 = U/\dot{U} \quad (11)$$

$$\text{and } T_2 = C/MlU \quad (12)$$

Steering control considerations

Thus we arrive at the linearized equations of motion of the uncontrolled vehicle. The problem is now to change the direction of the thrust in a rational manner in order to control the direction of the trajectory. This can only be done by measuring the variables, related variables, or their derivatives, in equations 8, 9 and 10. This is the arbitrary choice of the control engineer, who judges what is the best overall solution within his design specification, program, and budget. The more obvious possibilities are to measure the direction of the thrust relative to the fore-and-aft axis with an angular pick-off on the rocket-motor gimbals, assuming that the thrust-line lies along the motor axis. Similarly, θ can be measured with a free gyroscope, provided that the wander-rate is small, or ψ can be determined if an inertial platform is incorporated, with a similar proviso on the drift of the inertial reference. With rectilinear accelerometers, the missile's lateral accelerations can be measured, and, provided that small angles are assumed, this method provides y. Some combination of these will provide effective control (remember the theorem which states that the maximum number of controllers permissible before a redundancy occurs is equal to the number of degrees of freedom in the uncontrolled system). Clearly none of these measurements will be perfect, and the choice is largely determined by the effectiveness of already-developed instrumentation, and the prospects of new developments being ready in time for the final assembly of the rocket.

As already mentioned, because of the necessity to provide the minimum possible structure weight, the vehicle is inherently flexible to a very marked degree. The rocket behaves as an elastic beam with a fairly low natural frequency (e.g. the frequency published for the Thor missile is given as 6·95 c/s (7)). Thus the position of the kinematic instrumentation within the missile will determine the relation between the true motion of the missile and the flexural oscillation induced by changes in the lateral component of the thrust vector.

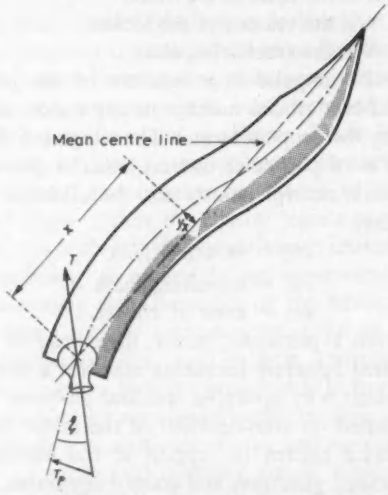
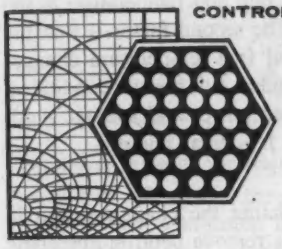


Fig. 2 Structural flexibility. If the motor is oscillated so that $\zeta = A \sin \omega_m t$, then $T_p = B \sin \omega_m t$. Hence $y_x = f$ (ω_m related to body frequencies) $\times$ $T_p \sin(\omega_m t + \alpha)$ $\times$ f (body geometry and homogeneity) and body angle with respect to centre lines as $\gamma_x = \partial y_x/\partial x$. These relationships depend entirely on the particular missile structure. However, y_x will produce spurious accelerometer signals, and γ_x will produce spurious gyroscope signals. The magnitude and sense of these signals will be determined by the situation of the instruments within the missile, the structure, the magnitude and spectrum of the existing forces

This can be a severe control problem since the natural frequency occurs within the guidance band-width, and without care the entire structure can become an unstable oscillatory loop as indicated in Fig. 2. Some alleviating measures are to determine the structural nodes and to place the instrumentation at these points. This tends to reduce the lowest interfering frequency, although it cannot entirely eliminate the higher structural harmonics, and furthermore these nodes will shift as the fuel tanks empty.

To be continued



CONTROLLING NUCLEAR POWER—5

In addition to the question of the overall stability of a reactor, there is also the problem of spatial stability

Stability considerations in power reactor systems

by **R. I. VAUGHAN**
U.K. Atomic Energy Authority

TO A CONSIDERABLE EXTENT THE REQUIREMENTS OF A power reactor control system are dependent on the type of reactor and on the use made of the power it generates. For example, the instrumentation and control mechanisms in a pressurized-water reactor differ from those in a gas-cooled graphite-moderated reactor, the heat transfer properties of the coolant and the behaviour of the reactor powers differing greatly. Again, there may be important differences between the control system in a large land-based reactor for a base-load electricity-generating system and that in a smaller reactor of the same type providing power for the propulsion of a ship; in the one case rapid changes between low power and full power may never occur, or may be regarded as rare, whereas, in the other case, large power changes are to be expected in normal operation.

In this article, an outline is given of the principles governing the choice of instrumentation and the requirements of the control system's performance from the point of view of stability rather than of safety.

Instrumentation

Whatever the reactor type (e.g., pressurized-water, boiling-water, gas-cooled graphite-moderated), the control instrumentation has to cover two main ranges of power level. One main range is that obtaining when the reactor is being started up or has been shut down, and the reactor power is insufficient to have a significant effect on temperatures. The other main range prevails when power changes have appreciable temperature effects.

In the first power range, it is only possible to determine the population of free neutrons within the core by nucleonic instruments (*1*)* such as ion chambers. Such instruments are generally located outside the reactor pressure vessel and measure the thermal neutron flux existing in 'thermal columns'. A **thermal column** is a block of moderator in which fast neutrons escaping from the reactor core and passing through the pressure vessel are slowed down. The low-energy neutrons escaping from the core are absorbed in the steel surrounding the reactor core.

As a rule, the purpose of measuring neutron flux during starting-up is to determine the state of the nuclear chain reaction in relation to criticality. [Recapitulating†: if the reactor is sub-critical (i.e. $k_e < 1$), the chain reaction is not self-sustaining and a neutron flux is only maintained in the core by neutron sources (mainly artificial) (*2*). If the reactor is critical, the chain reaction is self-sustaining, for as many neutrons are produced by fission as are absorbed within the reactor core or escape from the core ($k_e = 1$). If the reactor is super-critical, more neutrons are produced by fission than are lost by absorption or escape and the neutron population becomes ever-growing.]

* See also Dr Denis Taylor's article on nucleonic instrumentation in last month's issue of *Control*—EDITOR

† See the first article of the series, August 1960, p. 104—EDITOR

While the reactor is shut down, the nuclear chain reaction is sub-critical. In order to come up to power, the reactor must be made super-critical for periods of time. The nucleonic instrumentation is used during starting-up to measure the build-up of the neutron population and to ensure that the reactor does not become super-critical by a dangerous margin.

Once the reactor approaches operating powers, temperatures within the core become significantly influenced by power level. At power, the temperature rise of the coolant in passing through the core, with a Calder-type reactor, will be some 200 deg C. A good estimate of the power output of the reactor can then be obtained from measurements of the temperature rise and of the rate of flow of the coolant through the reactor core. Moreover, for best efficiency, the reactor must be run with the highest possible temperatures consistent with limits imposed by metallurgical or similar considerations. For example, there is a maximum permissible fuel-element-can temperature in a carbon-dioxide-cooled reactor; or, again, bulk boiling of the water is not permissible in a pressurized-water reactor. Thus it is certainly necessary to measure temperatures within the reactor core and there is an incentive to use temperature measurements for the main component of the error signal in any automatic control system regulating the chain reaction in the reactor core.

Control of the reactor at operating powers is also strongly influenced by certain effects of power output on k_e. In other words, there is an important inherent feedback of power into k_e. This feedback arises from the effects on k_e of:

1 The temperatures of the fuel and moderator

2 The build-up and decay of the isotope xenon-135, formed primarily in a decay chain starting with the fission product tellurium-135.

With the Calder-type reactor, the performance of the control system in terms of required speeds of response and the suitability of any measurement for a control signal is primarily determined by **1**. This is because the time lags between power and temperature changes are at most several minutes, whereas the time lags governing the xenon-135 concentrations within the fuel are several hours.

Factor **2** has an important influence on the stability of the distribution of the power output as distinct from the total power output within the core of a large thermal reactor. This is covered later in the present article.

The effect of temperature changes on k_e are described in terms of temperature coefficients of reactivity. With the Calder type of reactor, the fuel temperature coefficient of reactivity is about $-2 \times 10^{-5}\ \delta k/\text{deg C}$, where δk is the change in k_e. The moderator temperature coefficient of reactivity varies with fuel irradiation (*3*). Extreme values of the coefficient might be $-4 \times 10^{-5}\ \delta k/\text{deg C}$ when the fuel is unirradiated, and approaching $15 \times 10^{-5}\ \delta k/\text{deg C}$ at high irradiations. As will be shown later in this series, there are two factors enhancing the significance of the fuel temperature coefficient relative to the moderator temperature coefficient in determining reactor behaviour. The first is that the difference between the steady-state average fuel temperature for two different power levels is about $1\frac{1}{2}$ times to twice the change in average moderator temperature if the coolant flow rate and temperature at the reactor inlet are constant. The second factor is that the time lag between power and fuel temperature changes is only a few seconds under full-power conditions, whereas the time lag between power and average moderator temperature changes is several minutes.

Control absorbers

The usual method of regulating the chain reaction in a reactor core is to insert or remove neutron-absorbing materials. With the Calder type of reactor the control absorbers are in the form of rods of length roughly equal to the core height (about 20 ft). The rods are suspended on cables and are raised and lowered by winches powered by electric motors.

The total change in k_e which the control rods must be able to provide is governed by:

1 The need for an adequate margin by which the reactor is sub-critical when shut down at any stage of the reactor's life

2 Variation in k_e occurring in the reactor on changing from shut-down to operating conditions throughout the life of the core

An automatic control system need only deal with changes in k_e over times of less than a day with the reactor at operating powers. These changes are generally much less than the changes **1** and **2** above, so that only a small proportion of the control rods need be actuated by the automatic control system. The large changes in k_e to be accommodated by the control system can be met by a human operator switching groups of large numbers of control rod motors on and off.

Reactor kinetic equations

A simple set of equations, the 'reactor kinetic equations', relates the free neutron population within the core to k_e. The kinetic equations can be derived simply, although not rigorously, from the two balances:

(i) Rate of increase in neutron population = rate of production of prompt neutrons by fission + rate of appearance of delayed neutrons from neutron-emitting fission products − rate of absorption of neutrons in core materials − rate of escape of neutrons from core.

(ii) Rate of increase of number of nuclei of delayed-neutron emitter i = rate of production of nuclei of delayed-neutron emitter i from fission − rate of decay of delayed-neutron emitter i nuclei.

These balances yield:

$$\frac{dN}{dt} = k_e(1-\beta)\frac{N}{\tau} + \sum_i \lambda_i C_i - \frac{N}{\tau} \qquad \ldots (1)$$

and

$$\frac{dC_i}{dt} = k_e\frac{\beta_i N}{\tau} - \lambda_i C_i \qquad \ldots (2)$$

where N is the population of free neutrons in the core, β is the proportion of neutrons coming from delayed

neutron emitters, λ_i is the decay constant of delayed neutron emitter i, τ is the mean neutron lifetime, C_i is the number of nuclei of delayed neutron emitter i, and β_i is the contribution to β of this emitter.

Considering small perturbations, (1) and (2) yield the transfer function:

$$\frac{1}{n_o}\cdot\frac{\delta n(p)}{\delta k(p)} = \frac{1}{\tau}\cdot\frac{1}{p\left[1+\sum_i \frac{\beta_i}{\tau(p+\lambda_i)}\right]}$$

given in the second article of this series (Sep. 1960).

Instabilities in radial variation of power

The flow of coolant through each fuel channel in a power reactor is adjusted to give the highest temperature consistent with specific limitations at full-power conditions. Normally, total flow of the coolant through the core will be variable so that changes in power output are possible with roughly the same temperature distributions. However, variation in the distribution of the flow between the channels will not be possible. Thus it is essential that under operating conditions appreciable deviations in the radial distribution of the power output of the core should not occur.

With large power reactors and high fuel irradiations it is known that the shape of the power distribution across the core may be unstable if appropriate controlling action is not taken, even when the total power output is kept constant (*4*).

It is possible to give a simple qualitative explanation of the way in which an instability in the shape of the power distribution across the reactor core can arise. Also the way in which such an instability can be suppressed is easily explained in general terms.

Just as there is a balance for the neutron population in the whole core, so there is a balance for each region of the core. This may be written (neglecting delayed neutron effects):

Increase in number of neutrons in region in one generation $= \tau\frac{dn}{dt}$ = (number of neutrons produced in the region by fission) − (number of neutrons absorbed in region) − (net number of neutrons flowing out of region) $= (k_\infty - 1)n$ − (net flow out of region).

In this balance, n is the population within the region and k_∞ is the ratio of the number of neutrons produced in fission in one generation to the number of neutrons absorbed. In a reactor with uniform conditions everywhere there would be no net flow of neutrons out of any region and $k_e = k_\infty$.

Now the net flow of neutrons from one region into neighbouring regions is dependent on the differences in neutron density, neutrons diffusing from regions of high to regions of low density. Suppose that a reactor, after being in a steady condition for some period of time (i.e., $k_e = 1$) is subjected to a disturbance causing an increase in k_∞ over a small region of the core. The outward movement of a control rod would have such an effect. There will be two immediate consequences:

1 k_e for the whole core will become greater than unity so that the total neutron population will start increasing

2 Relative to the whole core, the proportion of neutrons produced near the region in which k_∞ has risen will be higher than in the steady condition. In other words, the shape of the neutron flux distribution will have changed with a greater proportion of the neutron population around the region with increased k_∞.

The first effect may be counteracted by, for example, increasing the penetration into the core of a number of control rods. The total neutron population of the core may then be held steady, but the change of shape of the neutron distribution will remain. However, immediately after the disturbance the influence of power on reactivity assumes major importance.

NEXT MONTH

The sixth article in the series will be 'Transient analysis of simple automatic controls for power reactors' by **W. G. Proctor** of the U.K. Atomic Energy Authority.

It has already been explained that k_e for the reactor depends on temperature conditions. In a similar manner, k_∞ for each region varies as temperatures within the region vary. Temperatures also affect the neutron **migration area,** a quantity proportional to the mean square distance between the points of birth and absorption of a neutron (*1*). A rigorous mathematical treatment shows that account is taken of the variation in neutron migration area if stability criteria are given in terms of temperature coefficients of reactivity rather than of temperature effects on k_∞. This distinction is not essential to understanding power instabilities in the Calder type of reactor and is neglected in the explanation of instabilities given below.

If k_∞ increases owing to the temperature changes following a power increase, and if, following a disturbance, control action leaves increments in the power outputs of some channels but decrements in the power outputs of others, so that total power stays constant, then:

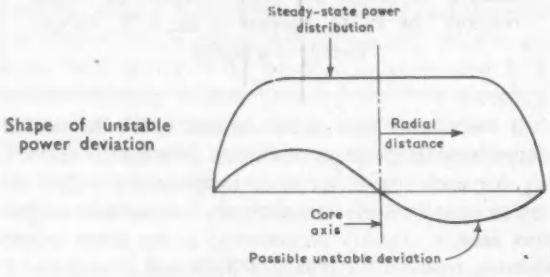
a changes in k_∞ due to the temperature changes will tend to increase the deviations in the power distribution,

b the tendency for neutrons to flow from regions of high neutron density to regions of low density will tend to suppress the excursion.

The significance of **b** depends on the shape of the steady-state neutron flux distribution and on the neutron migration area. A decrease in migration area tends to reduce the stabilizing influence of **b. Flattening** of the radial distribution of power, that is, inserting neutron-absorbing material in a region round the core axis so as to make the power distribution constant within a certain radius, also reduces effect **b** (*4*). If no attempt is made to stabilize the shape of the radial flux distribution, then effect **a** may outweigh effect **b,** and any disturbance will lead to a growing deviation

in the power distribution. The shape of the flux deviation immediately after the disturbance will depend on the disturbance, but, after a time, sharp peaks and depressions in the excursion will even out. The diagram shows the shape of the steady-state flux distribution along a diameter in a 'flattened' reactor, and the shape into which an unstable power deviation would evolve if total power were held constant by suitable control action. The variation in this power deviation round the core at a given radius is proportional to $\cos\theta$ where θ is the azimuthal angle relative to the radius along which the power deviations are greatest.

Even under the most adverse conditions in the largest reactors of the Calder type, excursions in power shape would only grow slowly. The time taken for the power to increase from, say, 105% to 110% of the steady power would be many minutes, even in channels where power is changing most rapidly. It should be mentioned



that the power distributions in the Calder reactors themselves are stable for all conceivable operating conditions.

Although the deviations in neutron flux only grow slowly when total power is adequately regulated, it is necessary that the control system be arranged to suppress any instabilities in shape. A straightforward method of achieving stability is to constrain any power excursions to shapes involving several maxima and minima so as to enhance effect **b**. This may be done by having a number (say nine) of independent automatic controllers, each having a control signal based on the average deviation in the power output from a number of channels in a region of the core and actuating one or two control rods. Thus the control system regulates the power output from each of a number of regions of the core and suppresses power deviations over large parts of the core.

In considering the stability of the total power output of the core, only effect **a** arises. Thus, if there were one control system to stabilize total power, and a separate control system to stabilize the shape of the power distribution, the minimum performance of the former in terms of speed of response and gain would be more stringent than that for the latter. In practice, the same controllers are likely to be used to regulate both total power and its variation across the core. The required performance of such controllers is then largely dictated by the need to regulate total power. Consequently, at least preliminary control studies may be made using a mathematical model in which the shapes of the neutron flux and coolant temperature distributions in the core are assumed to remain constant. A description of such studies is given later in this series of articles.

In determining the number and locations of the controllers it is necessary to take account of an effect additional to **a** and **b** above. This is the effect of fluctuations in xenon-135 concentrations. Xenon-135 is formed mainly from the decay of iodine-135 (half-life 6·7 h) which is formed from the fission product tellurium-135 (half-life 1 min). The fate of a neutron is sufficiently likely to be absorption in a xenon-135 nucleus for variations in xenon-135 concentrations to be significant in the neutron economy. The immediate effects of an increase in the free neutron density in any region of the core are an increase in the rate of production of tellurium-135, which soon leads to an increase in the production of iodine-135, and an increase in the rate of destruction of xenon-135 owing to the absorption of neutrons (the same absorption as that causing a drop in k_∞). Thus there is a rising concentration of iodine-135 and a falling concentration in xenon-135. The immediate effect is then de-stabilizing, and simply aggravates effect **a**. However, if the resulting instability is not too acute, the increased rate of creation of xenon-135 owing to the increased iodine-135 concentration may in time (several hours) outweigh the increased rate of destruction of xenon-135 owing to neutron absorption and the reduced rate of decay of xenon-135 (half-life 9·2 h). This introduces an effect tending to reduce the perturbations, and, under certain circumstances, oscillations may arise. Such oscillations can have any degree of damping or divergence covering a transition between stable and statically unstable conditions. However, over the range of conditions in which the response is recognizably oscillatory, the period of oscillations is governed by the half-lives of the iodine-135 and xenon-135 and is roughly one day.

Should instabilities arise only when the temperature effects **a** are augmented by this xenon poisoning effect, the corresponding excursions must be so slow as to permit regulation by manual control. Nevertheless, sufficient instrumentation must be provided to detect such instabilities if there is any possibility of their arising, and there must be the means of moving separate groups of control rods.

It is clearly desirable to have sufficient automatic controllers to retain stability even if one should fail. If, then, each controller is made electrically and mechanically independent of the others as far as possible, it should be possible to render quite remote the chance of having to shut a reactor down owing to failure of the control-rod control system.

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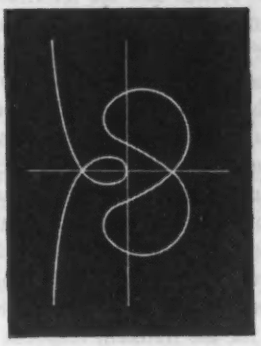


NUMBER FOUR OF A SERIES **PART A**

The root locus is a powerful method (far better than frequency response) for getting information about a system. It shows the effect of varying parameters, and leads easily to the transient response

Pole-zero approach to system analysis

by **P. F. BLACKMAN**

Imperial College of Science and Technology

CLOSED-LOOP SYSTEMS

A *closed-loop system* is one in which an output quantity is controlled by an input quantity, the essential feature being that direct modification of the output quantity is achieved by an *error* signal derived from comparison of input and output quantities. An actual system may be required to cause the output quantity to be controlled by a variable input, or to hold the output steady against disturbances in the output domain while the input remains substantially constant.

Whatever are the actual performance requirements of a system, it is a normal feature that the output powers controlled are greater than the error signal power, and that the error controls the output through a *forward path* containing power gain. The block diagram for such a system may be represented as in Fig. 1.

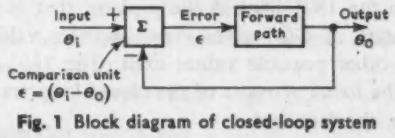


Fig. 1 Block diagram of closed-loop system

The forward path will vary widely in form and complexity, but it will be described by a differential equation and will have certain natural modes which are characteristics of the path. When the complete transfer from input to output under closed-loop conditions is considered, however, the natural modes of this transfer will be found to differ from those of the forward path, and an important aspect of system design is the investigation and control of closed-loop natural modes.

If the forward path is described by (say) a third-order differential equation

$$a_3\frac{d^3\theta_o}{dt^3} + a_2\frac{d^2\theta_o}{dt^2} + a_1\frac{d\theta_o}{dt} + a_0\theta_o = \epsilon$$

the natural modes and frequency response may be investigated by the complex frequency substitutions

$$\theta_o = \theta_o(p)e^{pt};\ \epsilon = E.e^{pt}$$

leading to the forward-path transfer function $\theta_o(p)/E(p)$.

When the overall transfer $\theta_o(p)/\theta_i(p)$ is required, the relation

$$\epsilon = (\theta_i - \theta_o)$$

may be substituted in the equation for the forward path, giving

$$a_3\frac{d^3\theta_o}{dt^3} + a_2\frac{d^2\theta_o}{dt^2} + a_1\frac{d\theta_o}{dt} + (a_0 + 1)\theta_o = \theta_i$$

and although the actual modification to the equation has been comparatively modest, namely the addition of unity to the final coefficient, this has the unfortunate effect of altering all the natural modes of the system

from those of the forward path alone. If the feedback path is not a direct link but may itself contain a system described by a differential equation, the modification becomes rather more drastic.

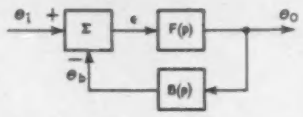


Fig. 2 General closed-loop system

If this more general case is considered, the differential equation for each portion may be converted into a transfer function in the complex frequency variable p, so that the system may be represented as in Fig. 2 where $\theta_o(p)/E(p) = F(p)$ and $\theta_b(p)/\theta_o/(p) = B(p)$, and the relation

$$E = (\theta_i - \theta_b)$$

makes the standard closed-loop transfer expression obtainable

$$\theta_o(p)/\theta_i(p) = F(p)/[1 + F(p)B(p)]$$

which in the case of direct feedback reduces to

$$\theta_o(p)/\theta_i(p) = F(p)/[1 + F(p)]$$

Since F, B, are both functions of p, system natural modes or poles of the transfer function occur for values of p, say p_k, such that

$$F(p_k) \,.\, B(p_k) = -1$$

since this causes the denominator to vanish.

METHODS OF ANALYSIS

The relations obtained above for closed-loop transfers, and the condition for closed-loop natural modes, are universal results which hold irrespective of whether the actual differential equations for the system are known or not; they may not be known, for example, when the transfer functions are obtained by direct frequency-response measurements.

The various design and investigation procedures, such as:

Nyquist and inverse Nyquist plots
Log modulus and phase plots against log frequency ('Bode diagrams')
Log modulus against phase-angle plots ('Nichols charts')
Root locus method

are effectively means of investigating possible solutions of the equation

$$F(p) \,.\, B(p) + 1 = 0$$

which governs the natural modes of the system.

There is a significant difference between the first three methods and the root locus method: the first three operate in terms of the sinusoidal frequency response and investigate the equation

$$F(j\omega) \,.\, B(j\omega) + 1 = 0$$

and can only give an exact result if a natural mode lies on the imaginary axis in the p-plane. In normal situations, with natural modes in the left half plane, frequency response methods provide a sufficiently exact estimation of the system's natural modes. In contrast, the root locus method operates directly with natural-mode values which are explicitly available.

Choice between the various methods depends considerably on the system and the information available. The great advantage of frequency response methods is that these can operate with empirical information obtained from test results without need to have detailed knowledge of the system's differential equations.

The root locus method, while depending on a knowledge of the system's differential equations, can yield much more information than frequency response methods in complicated or unusual situations, and is a powerful method for obtaining general information and perceiving effects of parameter variation. In addition, the method is easily adapted to the problem of obtaining expressions for the transient response of systems.

THE ROOT LOCUS METHOD

The closed-loop transfer for the case of direct feedback is given by

$$\theta_o(p)/\theta_i(p) = F(p)/[1 + F(p)]$$

and the closed-loop natural modes are given by values (p_k) such that

$$F(p_k) = -1$$

The forward path usually has the form

$$K \,.\, G(p)$$

where $G(p)$ is a frequency-dependent portion, and K is a real multiplier (i.e., frequency-independent), often a gain value determined by amplification which is substantially constant within the frequency range of the system. Thus the natural mode criterion becomes

$$K \,.\, G(p) = -1$$

or

$$\angle G(p) = 180°;\ |G(p)| = 1/\mathrm{K}$$

and values of p satisfying this pair of relations give the natural modes of the system.

If the pole-zero pattern for $G(p)$ is plotted in the complex plane, a complete network of constant-phase and constant magnitude lines covering the p-plane could be constructed, but in the present case the requirement that

$$\angle G(p) = 180°$$

immediately restricts possible values of p_k to those lying on the 180° lines in the p-plane, that is the 180° line system of $G(p)$ gives *every possible* value of p_k, and no other possible values exist. The 180° line system is the *locus of roots* of the closed-loop transfer. In addition, the fact that

$$|G(p)| = 1/K$$

means that the required values of p must also lie on the constant magnitude line $1/K$. Hence the closed-loop poles can *only* be located at intersections of 180° lines and $1/K$ magnitude lines as in Fig. 3, and with varying

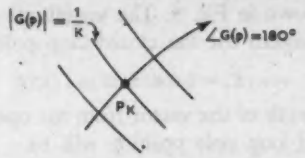


Fig. 3 Closed-loop pole position (p_k) determined by intersection of $\angle G(p) = 180°$, $|G(p)| = 1/K$

values of gain K the closed-loop poles move along the 180° lines of $G(p)$.

The root-locus method represents the extension of the complex frequency methods already described to the analysis of closed-loop systems.

EXAMPLES OF THE ROOT LOCUS METHOD

System with a single time-constant

For a system with a single time constant in the forward path and an associated gain value K_1, as in Fig. 4, the forward-path transfer can be written as

$$F(p) = \frac{K_1}{(1 + p\tau)} = \frac{K_1}{\tau} \cdot \frac{1}{(p + 1/\tau)} = K \,.\, G(p)$$

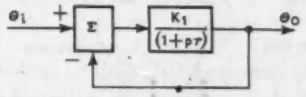


Fig. 4 Closed-loop system with a single time-constant in the forward path

The frequency-dependent portion of the path $G(p)$ has a single pole at $p = -1/\tau$ on the negative real axis in Fig. 5. There is a single 180°-line from the pole to infinity along the negative real axis, and the only possible closed-loop pole lies on this line at the point where

$$|G(p)| = |1/(p + 1/\tau)| = \tau/K_1$$

or inverting the relation

$$|p + 1/\tau| = K_1/\tau$$

which defines the length of the vector from the open-loop pole to a particular value of p which gives the closed-loop pole. From Fig. 5 the closed-loop pole will be located at

$$p = -(K_1/\tau + 1/\tau)$$

The graphical process carried out on the open-loop transfer has found the solution of

$$F(p) + 1 = 0$$

as the value

$$p = -(1/\tau)(K_1 + 1)$$

and if this is substituted into the actual closed-loop expression

$$\theta_o(p)/\theta_i(p) = K_1/(1 + p\tau + K_1)$$

the denominator will vanish.

To take specific values: if $\tau = 0{\cdot}25$ seconds and the forward gain K_1 is 10, then

$$F(p) = 10/(1 + 0{\cdot}25p)$$

or

$$K \,.\, G(p) = 10/0{\cdot}25(p + 4) = 40/(p + 4)$$

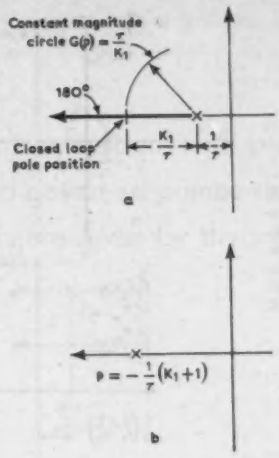


Fig. 5 (left) Patterns for the system of Fig. 4:
a open loop
b closed loop

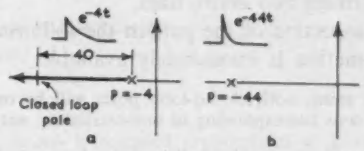


Fig. 6 (below) Numerical example of single-time-constant pattern with gain $K_1 = 10$: a open loop, b closed loop

The open-loop transfer has a pole at $p = -4$, and Fig. 6 shows the open- and closed-loop patterns. Closing the loop with a gain of 10 gives a pole at $p = -44$ corresponding to a time function

$$\exp(-44t)$$

compared with the open-loop pole at $p = -4$ corresponding to

$$\exp(-4t)$$

Although in this example the root locus method has been used to yield detailed information, an inspection of the open-loop pattern would immediately give the following qualitative information without any detailed analysis:

a Since the 180° line of the open-loop transfer lies along the negative real axis, the only possible closed-loop modes are non-oscillatory exponential forms.

b For increasing values of open-loop gain K_1, the closed-loop poles move to the left corresponding to a more rapidly decaying exponential as the natural mode.

System with two time-constants

For a system with two time-constants and a gain in the forward path, as in Fig. 7, the open-loop transfer becomes

$$K \,.\, G(p) = K_1/\tau_1\tau_2(p + 1/\tau_1)(p + 1/\tau_2)$$

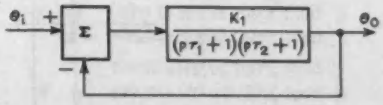


Fig. 7 System with two time-constants in the forward path

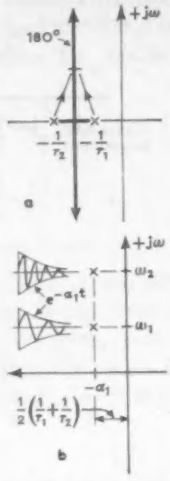


Fig. 8 a Open-loop 180°-lines for system with two time-constants. b Variation of closed-loop poles and natural modes with gain K

giving a 180° line system as in Fig. 8a, the lines in the plane being parallel to the imaginary axis, the whole system forming two *entire* lines.

From inspection of the pattern the following qualitative information is immediately available:

a For low gains, both closed-loop poles will be on the negative real axis corresponding to non-oscillatory natural modes.

b As the gain is increased the closed-loop modes become damped oscillations of the general form

$$\exp(-\alpha_1 t \pm j\omega_1 t)$$

where

$$\alpha_1 = (1/\tau_1 + 1/\tau_2)/2$$

which is independent of gain, so that gain variations alter the frequency of oscillation but not the actual damping envelope, and the system cannot become unstable.

c For values of gain such that the vectors from the poles become nearly parallel, the relation between gain and frequency will be

$$\omega \propto 1/\sqrt{K_1}$$

For an example, suppose

$$\tau_1 = 0{\cdot}25;\ \tau_2 = 0{\cdot}025;\ K_1 = 20$$

and it is required to determine the closed-loop natural modes. The open-loop transfer has poles on the negative real axis at -4, -40, and open and closed-loop poles are shown in Fig. 9. The magnitude value on the open-loop pattern for the closed-loop poles will be

$$\tau_1\tau_2/K_1 = 0{\cdot}00625/20 \simeq 1/3200$$

hence the length of the vector from the open-loop poles to the closed-loop pole position will be

$$\sqrt{3200} \simeq 56{\cdot}5$$

and the frequency of oscillation will be given by

$$\omega = \sqrt{(3200 - 18^2)} = 53{\cdot}5$$

and the closed-loop natural modes are

$$\exp(-22t \pm j53{\cdot}5t)$$

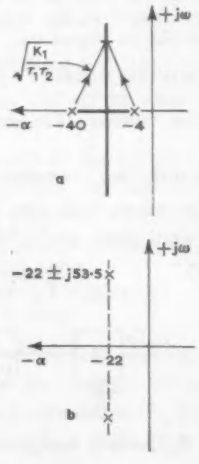


Fig. 9 Numerical example of two-time-constant system with gain K_1 20: a open loop, b closed loop

System with three time-constants

For the case of a system with three time-constants there are three poles on the negative real axis, with 180° line system as in Fig. 10.

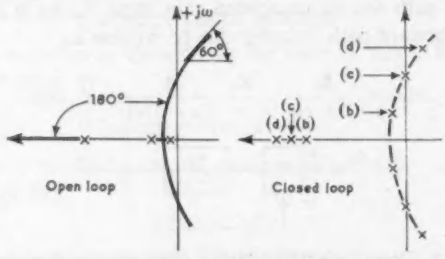


Fig. 10 Open- and closed-loop patterns for a three-time-constant system showing closed-loop pole motion with increasing gain: (b) acceptable transient response, (c) maintained oscillation, and (d) increasing oscillation

In this case the 180° line from the leading poles is deflected to the right owing to the influence of the additional pole. The line crosses the imaginary axis, eventually going to infinity at an angle of 60° to the positive real direction. There is also another 180° line from the additional pole to infinity along the negative real axis. For this system, with increasing gain the pair of closed-loop poles on the forward 180° lines become complex (b), reach the imaginary axis (c), and finally move into the right half plane (d), while the third closed-loop pole moves out along the negative real axis. Situation (b) may represent an acceptable transient response, while (c) represents maintained oscillations, and (d) a system in which oscillation amplitude will grow until some non-linearity causes limiting to occur.

Output units

The examples considered have contained only time constants in the forward path, but many systems terminate in actuators giving a mechanical displacement. Such actuators may be electric or hydraulic motors, rams or jacks etc., but are normally characterized by one or more integrations in the transfer between input signal and actual displacement.

Next month, in the second part of this article, Dr Blackman will consider examples of such output-units in some detail, discuss more general conditions, and show how loop-closure can be regarded as a redistribution of poles and zeros in the complex plane.

PART 4

Specimen calculations on systems with pressure-governed and Venturi-governed pumps show what sort of quantitative results are given by theory

Boiler feed discharge systems under changing load

by **A. J. MORTON, M.SC., A.M.I.MECH.E.**
Central Electricity Generating Board

Design without stability or response calculations is becoming inadequate. In previous parts of this article we made basic assumptions, looked at the discharge system in detail, discussed the characteristic equations for the combined pump and system, gave an account of the response of flow-rate to feed-regulator movement, considered the stability of the complete water-level loop, and gave a specimen calculation for a system with a constant-speed pump. Further specimen calculations are given below.

System with pressure-governed pump

Design data

Pump

Performance at 3000 rev/min as before. Characteristics for other speeds are shown in Fig. 5, calculated on the assumption

$$p_D \propto n^2 \text{ when } q \propto n \qquad (47)$$

where n = total rev/min measured from rest.

Moment of inertia of rotating parts (including turbine)	2500 lb/in²
Efficiency at design point (full load, 3000 rev/min)	0·6
$\frac{\text{No-load torque}}{\text{Full-load torque}}$ at constant speed	0·6

Torque:flow characteristics for various speeds are shown in Fig. 5, calculated on the assumptions

$$t_R \propto n^2 \text{ when } q \propto n \qquad (48)$$

where t_R = total pump torque at speed n and flow q, and

$$t_R - t_{R0} \propto q \text{ when } n \text{ is constant} \qquad (49)$$

where t_{R0} = no-load torque at speed n.

Turbine and governor

$\frac{\text{Standstill torque}}{\text{Full-speed torque}}$ (at constant governor-valve opening)	1·7

Driving torque is assumed proportional to governor valve opening at constant speed

Governor valve opening at 650 lb/in² gauge	0·5 in.
Governor valve opening at 750 lb/in² gauge	0 in.

(Opening varies directly with pressure between above limits).

The resulting curves of driving torque against governor valve lift are plotted in Fig. 7.

These data, together with those above, are sufficient to define the equilibrium operating line of the governed pump, which is plotted in Fig. 5.

Discharge system

Boiler and discharge pipe characteristics as under *System with constant-speed pump*, last month.

Feed regulator opening at full load	1 in.
Feed regulator pressure drop at full load	50 lb/in²

Lift:flow characteristic of regulator assumed linear in equilibrium. Pressure:flow characteristics of regulator plotted in Fig. 6 for various constant openings.

Estimation of constants of proportionality

Pump constants

From Fig. 5, pump discharge pressure increases by 39 lb/in² for every 75 rev/min increase in speed, at any constant flow Hence

$$K_P = \frac{39 \times 144 \times 60}{75 \times 2\pi} = 715 \text{ lb s/ft}^2 \qquad (50)$$

From Fig. 5 or equation 39,

$$K_Q = \left.\begin{array}{l} 92{,}000 \text{ lb s/ft}^5 \text{ at } 100\% \text{ load} \\ 46{,}000 \text{ lb s/ft}^5 \text{ at } 50\% \text{ load} \\ 9200 \text{ lb s/ft}^5 \text{ at } 10\% \text{ load} \end{array}\right\} \qquad (51)$$

From Fig. 5, and referring to the equilibrium speeds given below,

$$K_T = \left.\begin{array}{l} 1{\cdot}190 \text{ lb ft s at } 100\% \text{ load} \\ 1{\cdot}003 \text{ lb ft s at } 50\% \text{ load} \\ 0{\cdot}865 \text{ lb ft s at } 10\% \text{ load} \end{array}\right\} \qquad (52)$$

$$K_R = \left.\begin{array}{l} 199 \text{ lb s/ft}^2 \text{ at } 100\% \text{ load} \\ 189 \text{ lb s/ft}^2 \text{ at } 50\% \text{ load} \\ 186 \text{ lb s/ft}^2 \text{ at } 10\% \text{ load} \end{array}\right\} \qquad (53)$$

Turbine and governor constants

From Fig. 5, equilibrium speeds and governor valve openings are as follows:

LOAD	FLOW	SPEED	GOVERNOR VALVE LIFT
%	ft³/s	rev/min	in
100	0·470	3000	0·50
50	0·235	2845	0·345
10	0·047	2805	0·250

Using these data in Fig. 7,

$$K_G = \left.\begin{array}{l} 5600 \text{ lb at } 100\% \text{ load} \\ 5810 \text{ lb at } 50\% \text{ load} \\ 5860 \text{ lb at } 10\% \text{ load} \end{array}\right\} \quad (54)$$

$$K_D = \left.\begin{array}{l} 0.520 \text{ lb ft s at full load} \\ 0{\cdot}359 \text{ lb ft s at half load} \\ 0{\cdot}260 \text{ lb ft s at no load} \end{array}\right\} \quad (55)$$

the constants applying only to conditions in the neighbourhood of equilibrium at the load concerned.

By definition, governor valve closes half an inch for each 100 lb/in² rise in discharge pressure at any load, giving

$$K_W = \frac{0{\cdot}5}{12 \times 100 \times 144} = 2{\cdot}90 \times 10^{-6} \text{ ft}^3/\text{lb} \quad (56)$$

Discharge system and regulating valve constants

Referring to Fig. 5, equilibrium conditions in the discharge system are as follows:

LOAD %	FLOW ft³/s	REGULATOR OPENING, in.	PRESSURE DROPS, lb/in² PIPEWORK	REGULATOR	TOTAL
102	0·479	1·02	52·0	47	99
100	0·470	1·00	50·0	50	100
98	0·461	0·98	48·0	53	101
52	0·244	0·52	13·6	116	130
50	0·235	0·50	12·5	117	130
48	0·226	0·48	11·6	119	131
11	0·0517	0·11	0·6	149	150
10	0·0470	0·10	0·5	149	150
9	0·0423	0·09	0·4	150	150

At any fixed regulator opening, the total pressure drop varies with the square of the flow, the law at full load, for example, being

$$p_S = 144 \times 100(q/0{\cdot}47)^2 \quad (57)$$

$$K_S = \frac{dp_S}{dq} = \frac{2 \times 144 \times 100}{(0{\cdot}47)^2} q \quad (58)$$

corresponding results with different numerical constants being obtainable for other loads. Hence

$$K_S = \left.\begin{array}{l} 61{,}300 \text{ lb s/ft}^3 \text{ at } 100\% \text{ load} \\ 159{,}400 \text{ lb s/ft}^3 \text{ at } 50\% \text{ load} \\ 920{,}000 \text{ lb s/ft}^3 \text{ at } 10\% \text{ load} \end{array}\right\} \quad (59)$$

It remains to determine K_F, which is the decrease in system resistance per unit increase in regulator valve opening, *at constant flow*, and this can be done by considering small changes about any selected equilibrium point. At 98% load, for example, the system resistance is about 101 lb/in² with a flow of 0·461 ft³/s, and at any other flow q with the same regulator setting the resistance would be

$$101(q/0{\cdot}461)^2 \text{ lb/in}^2$$

With the regulator fixed at the equilibrium opening corresponding to 102% load, the resistance at flow q is

$$99(q/0{\cdot}479)^2 \text{ lb/in}^2$$

the difference between this and the preceding expression representing the decrease in resistance at flow q due to the increase in regulator opening from 0·98 to 1·02 in. Hence, taking the value of q corresponding to 100% load,

$$K_F = 144 \times \frac{12}{(1{\cdot}02 - 0{\cdot}98)} \times (0{\cdot}470)^2 \left\{ \frac{101}{(0{\cdot}461)^2} - \frac{99}{(0{\cdot}479)^2} \right\}$$

$$= 428{,}000 \text{ lb/ft}^3$$

Similar reasoning for changes in the regions of 50% and 10% load leads to

$$K_F = \left.\begin{array}{l} 428{,}000 \text{ lb/ft}^3 \text{ at } 100\% \text{ load} \\ 915{,}000 \text{ lb/ft}^3 \text{ at } 50\% \text{ load} \\ 5{,}440{,}000 \text{ lb/ft}^3 \text{ at } 10\% \text{ load} \end{array}\right\} \quad (60)$$

Results

Estimation of time constants

The constants estimated above are collected in Table I (last month, p. 96), and on insertion of the appropriate values into equation 20 the following results are obtained.

For 100% loads:

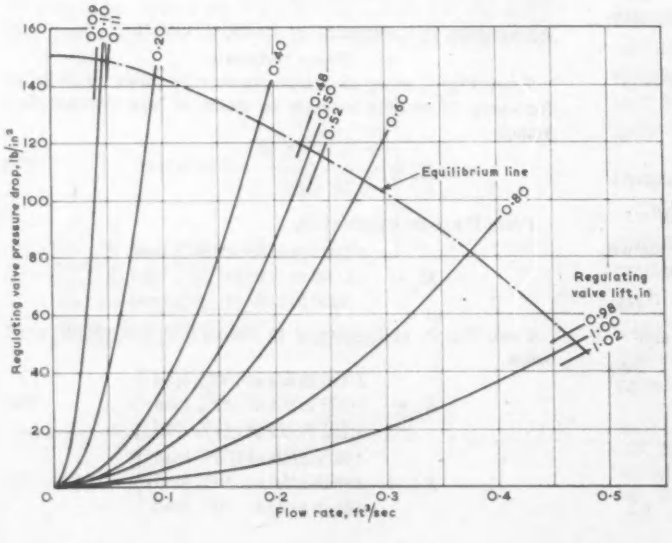
$$[1 + 0{\cdot}1397D + 0{\cdot}00266D^2]\, Q = 0{\cdot}00064\, T_0 + 5{\cdot}11[1 + 0{\cdot}0404D]y$$

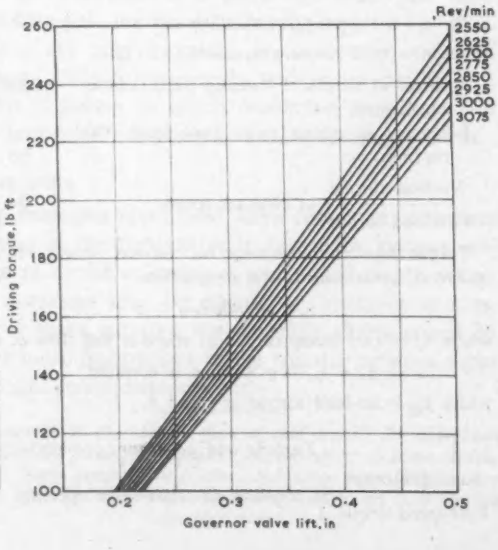
or

$$[(1 + 0{\cdot}117D)(1 + 0{\cdot}023D)]\, Q = 0{\cdot}00064\, T_0 + 5{\cdot}11[1 + 0{\cdot}040D]y \quad (61)$$

Fig. 6 (below, left) Feed regulating valve characteristics (pressure-governed system)

Fig. 7 (below) Driving turbine characteristics





For 50% load:

$$[1+0{\cdot}0790D+0{\cdot}00127D^2]\,Q = 0{\cdot}000306\,T_0+5{\cdot}25[1+0{\cdot}0402D]y$$

or

$$[(1+0{\cdot}056D)(1+0{\cdot}023D)]\,Q = 0{\cdot}000306\,T_0+5{\cdot}25[1+0{\cdot}040D]y \quad (62)$$

For 10% load:

$$[1+0{\cdot}0464D+0{\cdot}000240D^2]\,Q = 0{\cdot}0000579\,T_0+5{\cdot}84[1+0{\cdot}0406D]y$$

or

$$[(1+0{\cdot}040D)(1+0{\cdot}006D)]\,Q = 0{\cdot}0000579\,T_0+5{\cdot}84[1+0{\cdot}041D]y \quad (63)$$

Comparison with equation 29 gives the values of T_1, T_2, T_3 and C_1 shown in Table II (last month, p. 96). If the arithmetic is carefully checked, certain minor inconsistencies will be found, owing to the fact that some of the calculations are necessarily based on the small difference of two large quantities, and to avoid these errors the detailed arithmetic would have had to be performed with an accuracy quite unwarranted by the simple nature of the basic theory. Consequently the errors have been allowed to stand.

Interpretation

All the time constants in Table II are small, and the system would give no trouble in practice. No response curves have been drawn, since for oscillations of the frequencies likely to be encountered in practice the phase lag between flow rate and regulating valve lift would be negligible. At low loads, T_1 and T_2 diminish greatly, giving even greater stability and quicker response.

System with Venturi-governed pump

Design data

Pump

Curves of discharge pressure and torque against flow are the same as before, and are plotted in Fig. 5.

Turbine and governor

Turbine data are as before.

Governor arranged as in Part I (Nov. 1960), p. 99, Fig. B, and designed to give discharge pressure of 650 lb/in² at 0·47 ft³/s (3000 rev/min) and 600 lb/in² at no load (2595 rev/min), thus giving 50 lb/in² pressure drop across feed regulator at both full load and no load. This requires:

Governor valve opening at full load	0·500 in.
Governor valve opening at no load	0·205 in.

For ease of comparison, assume same governor spring as before.

Discharge system

General specification as in previous cases, but this will now lead to a different regulating valve since the available pressure drop across the valve is less than before except at full load. Pressure/flow characteristics are plotted in Fig. 8.

Estimation of constants of proportionality

Pump, turbine and governor constants

Owing to the different equilibrium pressure: flow and torque:flow characteristics produced by the new governor, slight changes will appear in some of the pump constants K_P, K_Q, K_R and K_T, and the turbine and governor constants K_D, K_G and K_W. These changes will not be calculated, as such exactness would not be justified in any practical case, and the above constants will all be assumed to have the same values as before (see Table I). A new governor constant K_Y, representing the Venturi action which now appears, is estimated below.

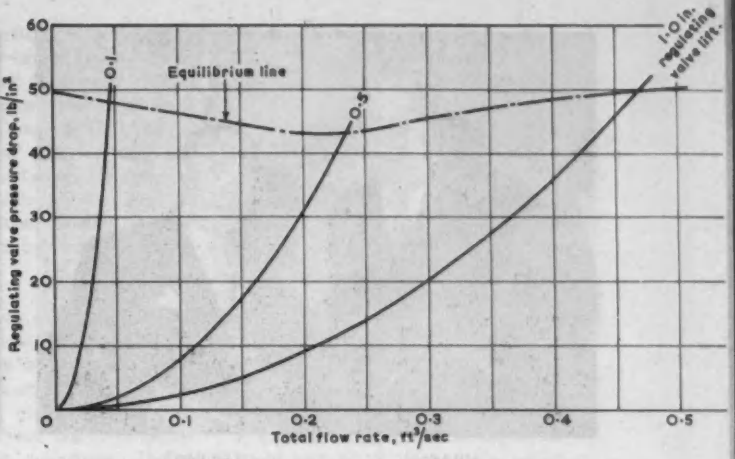


Fig. 8 Feed regulating valve characteristics (Venturi-governed system)

At no load, pressure alone is operative, and gives a governor valve opening of 0·205 in. In changing from no load to full load, pressure rises by 50 lb/in², which in absence of Venturi element would close governor valve by 0·250 in. (see previous example), whereas the governor valve actually opens further to 0·500 in. when pressure and Venturi elements act together. Additional opening due to Venturi element is therefore

$$0{\cdot}250 + (0{\cdot}500 - 0{\cdot}205) = 0{\cdot}545 \text{ in.}$$

The additional opening, being proportional to q^2, is therefore given at other loads by

$$0{\cdot}545(q/0{\cdot}47)^2 \text{in}$$

its range of change with respect to q being

$$\frac{2\times 0{\cdot}545}{(0{\cdot}47)^2}\,q \text{ in. per ft}^3/\text{s}$$

Hence

$$K_Y = \frac{2\times 0{\cdot}545}{12\times(0{\cdot}47)^2}\,q = 0{\cdot}411\,q \text{ s/ft}^2 \quad (64)$$

leading to

$$K_Y = \left.\begin{array}{l} 0{\cdot}1932 \text{ s/ft}^2 \text{ at } 100\% \text{ load} \\ 0{\cdot}0966 \text{ s/ft}^2 \text{ at } 50\% \text{ load} \\ 0{\cdot}0193 \text{ s/ft}^2 \text{ at } 10\% \text{ load} \end{array}\right\} \quad (65)$$

The equilibrium pressure:flow characteristic to which this governor gives rise is plotted in Fig. 5.

Discharge system and regulating valve constants

Equilibrium conditions in the discharge system can be read from Fig. 5 and are now as follows:

LOAD %	FLOW ft³/s	REGULATOR OPENING, in.	PRESSURE DROPS, lb/in² PIPEWORK	REGULATOR	TOTAL
102	0·479	1·02	52·0	50	102
100	0·470	1·00	50·0	50	100
98	0·461	0·98	48·0	50	98
52	0·244	0·52	13·6	44	58
50	0·235	0·50	12·5	43	56
48	0·226	0·48	11·6	43	55
11	0·0517	0·11	0·6	48	49
10	0·047	0·10	0·5	48	49
9	0·0423	0·09	0·4	48	49

Using the method already described

$$K_S = \left.\begin{array}{l} 61{,}300 \text{ lb s/ft}^5 \text{ at } 100\% \text{ load} \\ 68{,}600 \text{ lb s/ft}^5 \text{ at } 50\% \text{ load} \\ 300{,}000 \text{ lb s/ft}^5 \text{ at } 10\% \text{ load} \end{array}\right\} \quad (66)$$

$$K_T = \left.\begin{array}{l} 162{,}000 \text{ lb/ft}^3 \text{ at } 100\% \text{ load} \\ 262{,}000 \text{ lb/ft}^3 \text{ at } 50\% \text{ load} \\ 1{,}720{,}000 \text{ lb/ft}^3 \text{ at } 10\% \text{ load} \end{array}\right\} \quad (67)$$

To be continued

CONTROL **19** SURVEY

PRESSURE TRANSDUCERS

by **H. K. P. NEUBERT, DR-ING**

R.A.E., Farnborough

THIS SURVEY of British-made pressure transducers includes those with electrical outputs, but not acoustic pressure receivers (microphones or hydrophones) and pressure switches. The information in the table has been extracted from questionnaires completed by the manufacturers, supplemented in some cases by additional information available to the writer. Below are a few explanatory notes.

SECTION I—**General**

Name of manufacturer: in some cases the transducer may have been developed at a Government establishment, or be produced under licence from a foreign firm. Dimensions and weight are approximate, and may be subject to variation.

SECTION II—**Input**

In column 4, *gauge* means pressure relative to ambient (usually atmospheric) pressure; *differential* means a difference of two individually unknown pressures; *absolute* means pressure relative to vacuum. Admissible pressure media are given in the broadest possible terms; see column 21 for information about suitability for corrosive fluids. Only extreme pressure ranges have been quoted in column 5; a wide range of intermediate ranges is normally available. If the transducer can withstand a higher line-pressure than its range indicates, maximum line-pressure is quoted in column 7.

SECTION III—**Output**

Because of the great variety of transducer principles employed, and ranges quoted, column 9 gives the most useful information on either sensitivity or full-scale output. Linearity (column 10) is the maximum deviation (expressed as percentage of f.s.d.) at any point on the calibration curve, from an optimum straight line drawn through all points of calibration. In case of an inherently non-linear relationship a calibration curve will normally be supplied by the manufacturer. Accuracy (more precisely repeatability) quoted in column 11 is the error (expressed as percentage of f.s.d.) obtained in repeated runs of calibration, including errors due to hysteresis and creep, but excluding environmental errors (see section IV). The dynamic response (column 12) of a pressure transducer to sinusoidal, pressure fluctuations or to pressure transients is more often than not determined by its acoustic input-impedance, i.e. size of inlet tube and transducer cavity. It also depends greatly on the pressure medium employed. The resonant frequency of the diaphragm may only serve to determine the ultimate upper limit. Additional length of inlet pipes fitted to the transducer will usually reduce the useful frequency range of the transducer. Column 13: in order to avoid non-linearity or non-uniform frequency-response the output impedance of the transducer and the input impedance of the following circuit require matching.

SECTION IV—**Environment**

Column 14 gives the safe minimum and maximum ambient temperatures which will not permanently impair the calibration of the transducer. With water-cooled transducers the maximum ambient temperature depends also on the efficiency of the cooling system. In columns 15 and 16 zero shift and variation of sensitivity with temperature in per cent of full scale are average values only. They are usually not constant over a wide temperature range, and tend to increase with temperature. Column 17 gives the maximum acceleration (in terms of earth gravitation) which can be applied without permanently impairing the calibration of the transducer. Column 18 gives mean calibration errors, also related to gravity.

SECTION V—**Instrumentation systems**

The instrumentation system or systems for which the transducer is intended are described in broad terms in column 20.

SECTION VI—**Applications and remarks**

This covers examples of typical applications, and any further relevant information such as special features, suitability for corrosive media, etc. (column 21).

Although the range of pressure transducers now commercially available in this country is adequate for the majority of applications, in some cases, especially in the research regions of science and technology, there is room for further development. A recent survey by the Aircraft Data Reduction Committee of the S.B.A.C. on transducer usage and requirement (*1*) has come to conclusions similar to those the initiated reader may deduce from the present survey. With respect to pressure transducers, the requirements may be stated in broad terms: force-balance transducers of high accuracy and fast response; digital-output transducers of small size; low-range transducers with fast response and low sensitivity to acceleration; transducers for use at extreme ambient temperatures; transducers having very fast responses.

The general tendency of transducer development and usage is towards greater accuracies, say better than 1% f.s.d., and towards faster performance and smaller size. General-purpose pressure transducers with digital output will probably soon be wanted on a wide scale in order to facilitate data reduction (computation, data storage, deferred analysis). It is also obvious that any further transducer development must be matched by an improvement in associated electronic equipment and more sophisticated calibration techniques.

Reference

1. Report on 'Trace Recording Equipment and Transducers used in the Aircraft Industry' (April 1959), S.B.A.C., 29 King Street, St James, London, S.W.1.

Pressure transducers with electrical outputs

I—GENERAL			II—INPUT				III—OUTPUT						IV—ENVIRONMENT						V—INSTRUMENTATION SYSTEM	VI—APPLICATIONS AND REMARKS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
TYPE NUMBER	SIZE INCHES	MASS	PRESSURE AND PRESSURE MEDIUM	PRESSURE RANGE	OVER-LOAD RATIO %	MAX LINE PRESSURE	PRINCIPLE OF OPERATION	SENSI-TIVITY	LINEAR-ITY	AC-CURACY	FRE-QUENCY RANGE OR RISE TIME	RECOM-MENDED INPUT IMPEDANCE OF FOLLOWING CIRCUIT	OPERA-TIONAL TEMPERA-TURE RANGE	ZERO-SHIFT WITH TEMPERA-TURE	SENSI-TIVITY VARIATION WITH TEMPERA-TURE	MAX OPERA-TIONAL ACCELER-ATION	ERRORS DUE TO STATIC OR DYNAMIC ACCELER-ATION	OPERA-TIONAL HUMIDITY RANGE	CHARACTER OF INSTRU-MENTATION SYSTEM AND RECOMMENDED EQUIPMENT	TYPICAL APPLICATIONS AND REMARKS
Boulton Paul Aircraft																				
G41/100 ★716	3×2 dia	1·5 lb	Gauge	0–100 lbf/in²							>12 kc/s									
G41/500 ★717	3×2 dia	1·5 lb	Gauge	0–500 lbf/in²	50	—	Foil strain-gauge on diaphragm	1·2mV/V	1%	1%	>23 kc/s	—	20–40°C	1% total	Negligible	—	—	—	d.c. operated, or carrier amplifier systems	Hydrodynamic and hydraulic research. Test-rig instrumentation. Frequencies in col. 12 indicate diaphragm resonance
G41/5000 ★718	3×2 dia	1·5 lb	Gauge	0–5000 lbf/in²							>30 kc/s									
Evershed and Vignoles																				
ER.48 ★719	11×12·5 ×8·25	20 lb	Gauge (gas and liquid)	0–25 inH₂O to 0–10 lbf/in²	—	—	Force-balance, on-off controlled	0–15mA full-scale output (normal)	—	1%										Process control systems. Pressure range quoted is for capsule operation; range may be extended to 4500 lbf/in² by using Bourdon tubes
ER.83 ★720	10·25×8·5 ×8	13 lb	Differential (gas)	0–1·5 to 0·48 inH₂O	100	30 lbf/in²														Process control systems. Obtainable with built-in square-law for flow measurements and with bi-directional output
ER.109 ★721	14×11×8	15 lb	Differential (gas)	0–0·15 to 0–1·0 inH₂O	50	10 lbf/in²														Process control systems. Obtainable with built-in square-law for flow measurements. Built-in electric indicator
ER.125 ★722	13×7·5 ×9	19 lb	Differential (gas)	5–50 inH₂O 20–200 inH₂O 80–800 inH₂O	300	500 lbf/in² 1000 lbf/in² 1000 lbf/in²					2s for full scale	—	Up to 60°C (special 100°C)	—	—	—	—	—	Evershed's electronic repeater and 3-term electronic process control systems, d.c. circuits, non-interacting 3-term controls	Process control systems. Obtainable with built-in square-law for flow measurements. 10 : 1 range adjustment possible
ER.126 ★723	10·5×8·5 ×8	18·5 lb	Gauge and suction (gas and liquid)	0–6 to 0–4000 lbf/in²	50	Up to 3000 lbf/in²	Force-balance, on-off controlled	0–15mA full-scale output (normal)	±1%	±1%										Process control systems
ER.142 ★724	10·25×4·5 ×8	20 lb	Absolute (gas)	30–3 inHg 30–10 inHg	2000	—														Process control systems. Designed for low absolute pressures
ER.145 ★725	10×15 ×10	35 lb	Pressure head (liquids)	2–20 ftH₂O 6·5–60 ftH₂O	100	—														Process control systems. 10 : 1 range adjustment possible. For open or closed tanks
ER.148 ★726	13×7·5 ×9	19 lb	Flow pressure (reversible) (gas)	−2 to +2 lbf/in² −20 to +20 lbf/in²	1000	—														Process control systems. Built-in square-law
ER.149 ★727	13×7·5 ×9	17 lb	Absolute (gas and liquid)	15–150 lbf/in² 45–450 lbf/in²	100	—														Process control systems. 10 : 1 range adjustment possible. Obtainable with bi-directional output
Fielden Electronics																				
CTX 2 ★723	10·5×9 ×6·5	25 lb	Gauge (gas and	0–10 to	300	—	Force-balance, capacitance-	0–15mA full-scale	<0·7%	0·25%	0·5s	0—250 Ω	−15 to +45°C							

			liquid)	0–30 inH_2O			controlled	output					<0·05%/ degC									
CTX 3 ★729	10·5×9 ×6·5	24 lb	Gauge (gas and liquid)	0–30 to 0-15,000 lbf/in²	180	—	Force-balance, capacitance-controlled	0–15mA full-scale output	<0·4%	0·25%	0·5s	0—250 Ω	−15 to +45°C									
Ut 7 ★730	8×4 dia	3·5 lb	Gauge, absolute	0–5 inH_2O to 150 lbf/in²	200	—									Nil	—	--	0–95%	Fielden measuring, recording and control systems	Measuring, recording and controlling systems. Remote transmission. Process control. For most corrosive fluids. Suitable for operation under intrinsic safety conditions		
Ut 13 ★731	8×6 ×2·25	4·5 lb	Gauge	0–150 to 0-15,000 lbf/in²	200	—	Diff. transformer and demodulator and amplifier	0–15mA full-scale output	<0·5%	0·25%	0·2s	0—250 Ω	−15 to +45°C	<0·02%/ degC								
Ut 9 ★732	9×7 dia	11 lb	Differential	0–10 inH_2O to 0–150 lbf/in²	Full line-pressure	2000 lbf/in²								<0·03%/ degC								
Graseby Instruments																						
GI 366 ★733	1·02×2·35 dia	7·5 oz	Gauge	0–50 to 0–6000 lbf/in²	25	—	Potentio-meter, Bourdon tube	—	1%	1·5%	100–300 c/s	—	−40 to +80°C	0·01%/ degC	Nil	80g	<1% at 20g	Hermeti-cally sealed	Measuring and recording, telemetry	General, missiles. For non-corrosive fluids		
GI 478 ★734	2·5×2·25 dia	11·5 oz	Absolute	0–40 lbf/in²	50	—	Potentio-meter, Bourdon tube	—	0·5%	0·5%	100 c/s	—	−40 to +80°C	0·01%/ degC	—	100g	—			General, missiles		
K.D.G. Instruments																						
K.D.G. AD/14 (T.D.216) ★735	1·2×2·5 dia	8 oz	Gauge	0–100 to 0–6000 lbf/in²	10	—	Potentio-meter, Bourdon tube	—	±1% (−20 to +60°C)	—	—	>100k Ω	−40 to +80°C	—	<0·05%/ degC	X and Y axis: 30g Z axis: 80g	<0·2%/g	Sealed	General	General, aircraft, missiles. Beryllium copper tube, also stainless steel tubes. Shockload of 100g for 5 ms		
Kelvin and Hughes																						
KTG 1302 ★736	0·812× 1·75×1·75	5 oz	Gauge differential	0–30 lbf/in²	50	30 lbf/in²	Inductance	50% change of inductance	Calibration curve supplied	1%	2500 c/s	—	−40 to +85°C	Max 5% over full temperature range	Negligible	>30g	0·08%/g	0–100%	Variable inductance in oscillator tank circuit, (frequency modulation)	Telemetry, aircraft, missiles. For non-corrosive fluids. Frequency in column 12 indicates diaphragm resonance		
KTG 1303 ★737	0·812× 1·75×1·75	5 oz	Gauge differential	0–70 lbf/in²	50	70 lbf/in²											0·05%/g	0–100%				
KTG 1304 ★738	0·812× 1·75×1·75	5 oz	Gauge differential	0–100 lbf/in²	50	100 lbf/in²											0·03%/g	0–100%				
KTG 1313 ★739	0·812× 1·75×1·75	5 oz	Gauge differential	0–200 lbf/in²	50	200 lbf/in²											0·02%/g	0–100%				
KTG 1801 ★740	8·5×5·3 ×2	3·5 lb	Gauge (air)	0–30·8 inHg	50	1 atm	Force-balance, inductance-controlled	20 or 150 turns of output-shaft	0·1%	0·1% (20°C)	20s for full scale	—	−40 to +70°C	0·15%	—	12g	To be A/V mounted	0–100%	For use with pointer, potentiometer, digitizer, or synchros	Aircraft computers, telemetry, industrial control. May be used for certain corrosive gases. Total temperature error for range −26°C to +55°C, *see column* 15		
KTG 1901 ★741	8·5×5·3 ×2	3·5 lb	Absolute (air)	0–32·483 inHg	50	1 atm																
KTG 0101 ★742	3·25×3·25 ×3·78	15 oz	Double unit; gauge absolute	0–19·5 inHg 3–30 inHg	50	1 atm	Potentio-meter, capsules	—	1·5%	2·5%	1s	>1M Ω	−65 to +55°C	—	—	8g	Within spec. at 3g	0–100%	General	Aircraft, missiles and with computing systems. For air		
KTG 0201 ★743	3·25×3·25 ×3·37	11 oz	Gauge	7–85 inHg																		
KTG 0301 ★744	3·25×3·25 ×3·78	15 oz	Double unit: two absolute	0–30 inHg (each)																		
New Electronic Products																						
1029 ★745	1·6×1·7 dia	11 oz	Gauge	0–5 to 0–6000 lbf/in²	100	15,000 lbf/in²	Inductance	6% change of inductance	0·5%	0·5%	—	—	0–200°C	0·0075%/ degC	0·02%/ degC	30g	—	≤95%	Measuring and recording, New Electronic Products' carrier amplifiers and recorders	General, airborne pressure-measurements. For all fluids		
1028 ★746	1·875×1·6 dia	17 oz	Differential	0–5 to 0–5000 lbf/in²	100	10,000 lbf/in²							0–200°C	0·01%/ degC	0·02%/ degC	30g	—	≤95%		General, airborne pressure-measurements. For most fluids		
1025 ★747	2·25×1·6 dia	20 oz	Differential	0–20 lbf/in²	200	100 lbf/in²	Inductance	—	0·5%	0·5%	—	—	0–60°C	0·02%/ degC	0·02%/ degC	30g	—	—		Blood pressure, heart diagnosis, surgery. For use with liquids in medical field		
Salford Electrical Instruments																						
T.B.B. ★748	7·13×4·85 dia	5 lb	Gauge	0–25 inH_2O to 0–300 lbf/in²	100	—	Inductance	1–0–1V output full scale	±1%	—	—	—	−40 to +70°C	<1%	—	—	—	Unsuit-able for extremes	Salford dynamometer indicating systems, also with self-balancing recorders	Process control, power station instrumentation. Figure in column 10 indicates total error. Figure in column 15 indicates total temperature error when used with recommended equipment		
B.T. ★749	4×7·1 dia	5·25 lb	Gauge	0–300 to 0–6000 lbf/in²	100																	
D.P. ★750	6·7×4 dia	13 lb	Differential	0–100 inH_2O to 0–300 lbf/in²	100	3000 lbf/in²	Differential transformer															
A ★751	—	—	Absolute	0–100 mmHg to 0–300 lbf/in²	100	—																
Sangamo Weston																						
S.122 ★752	Various	8–13 oz	Gauge	0–40 to 0–6000 lbf/in²	—	—	Potentio-meter	—	—	±3% total	—	—	—	—	—	—	—	—	Ratiometer indicators	Oil-, fuel- and air-pressures in aircraft		
Saunders Roe																						
																			Indication:	General		

A ★751	—	—	Absolute	0–100 mmHg to 0–300 lbf/in²	100	—															

Sangamo Weston

S.122 ★752	Various	8–13 oz	Gauge	0–40 to 0–6000 lbf/in²	—	—	Potentio-meter	—	—	±3% total	—	—	—	—	—	—	—	—	—	Ratiometer indicators	Oil-, fuel- and air-pressures in aircraft

Saunders Roe

PT.1 ★753	2·75×3·13 dia	1·25 lb	Gauge	0–25 to 0–500 lbf/in²	150	—	Strain gauge	2·5mV/V full scale	±0·2%	±0·2%	0–200 c/s	≥25 kΩ	−40 to +70°C	—	—	—	—	0–85%	Indication: Saunders Roe transistor amplifier and meter unit. Recording: Galvanometer recorders, e.g. New Electronic Products	General. For fluids compatible with aluminium alloys. Also for differential pressure
PT.90 ★754	2·0×0·63 dia	1 lb	Gauge	0–500 to 0–1000 lbf/in²							0–500 c/s	≥25 kΩ	−40 to +600°C								For use at high ambient temperatures (under development)

S.E. Laboratories

S.E.50 ★755	1·5×1·75 ×1	5 oz	Gauge, differential, absolute	0–1 to 0–2000 lbf/in²	300 to 1000	3000 lbf/in²	Inductance	10% change of inductance	<±0·25%	<±0·25%	700 c/s	>200 Ω					$\frac{0·7}{p^3/_8}$%/g	—	Closed-loop control circuits, measuring and recording, employing S.E. Lab. system of a.c. bridge, amplifier, demodulator and recorder, or other suitable carrier systems	Process-control, industrial pressure-measurement, aircraft, missiles. For insulating and non-corrosive fluids only. In the equations in column 18, p represents pressure range
S.E.65 ★756	2×1·13 ×1·5	8 oz	Gauge, differential, absolute	0–2000 to 0–6000 lbf/in²	300 to 1000	8000 lbf/in²											$\frac{0·35}{p^3/_8}$%/g	—		
S.E.70 ★757	0·85×1 ×0·75	2·5 oz	Gauge, differential, absolute	0–2 to 0–400 lbf/in²	300 to 1000	1000 lbf/in²	Inductance	7% change of inductance									$\frac{1·2}{p^3/_8}$%/g	—		
S.E.50C ★758	1·5×1·75 ×2·5	13 oz	Gauge, differential, absolute	0–5 to 0–2000 lbf/in²	300 to 1000	3000 lbf/in²	Inductance	10% change of inductance					−40 to 120°C	<0·02%/degC	<0·02%/degC	1000g	$\frac{2}{p^3/_8}$%/g	—		Process control, industrial pressure-measurement, aircraft, missiles. For all corrosive fluids
S.E.60 ★759	1·5×1·75 ×1·25	6 oz	Gauge, differential, absolute	0–5 to 0–2000 lbf/in²	300 to 1000	3000 lbf/in²	Inductance	10% change of indu.tance	<±0·25%	<±0·25%	700 c/s	—					$\frac{1·2}{p^3/_8}$%/g	—	Two coils form part of oscillator tank circuit (f.m.). For use with S.E. Lab. transistorized equipment, producing 1–5 kc/s f.s. frequency deviation	Telemetry. For insulating and non-corrosive fluids only
S.E.57 ★760	2×2 ×2·25	10 oz	Gauge, differential, absolute	0–5 to 0–3000 lbf/in²	300 to 1000	4000 lbf/in²	Inductance	6V d.c. output full scale	<±0·5%	<±0·5%	700 c/s	<10k Ω	−40 to +80°C	<0·02%/degC	0·02%/degC	1000g	$\frac{0·7}{p^3/_8}$%/g	—	Built-in demodulator	General, telemetry. For insulating and non-corrosive fluids only
S.E.58 ★761	2×2 ×2·25	10 oz	Gauge, differential, absolute	0–5 to 0–3000 lbf/in²	300 to 1000	4000 lbf/in²	Inductance	6V d.c. output full scale	<±0·5%	<±0·5%	100 c/s	<10k Ω or 50 Ω	−40 to +80°C	<0·02%/degC	0·02%/degC	1000g	$\frac{0·7}{p^3/_8}$%/g	—	Built-in oscillator and demodulator	
S.E.49 ★762	1·75×1·75 ×2	10 oz	Gauge, differential, absolute	0–20 to 0–1000 lbf/in²	300	1500 lbf/in²	Differential transformer	10V r.m.s. for full scale	<±0·5%	<±2%	—	—	−40 to +100°C	<0·02%/degC	0·02%/degC	1000g	$\frac{3}{p^3/_8}$%/g	—	For use with a.c. ratiometer indicator (50 to 400 c/s)	Aircraft oil-pressure indicator. For all corrosive fluids

Solartron Electronic Group

NT4–313 ★763	0·85×0·65	1·5 oz	Gauge, differential, absolute	0–10 to 0-10,000 lbf/in²	150	150 lbf/in²	Un-bonded strain gauge	4m V/V for full scale	0·35%	0·2%	0–12 kc/s	≥50 Ω	−195 to +150°C	0·018%/degC	0·018%/degC	100g	<0·01%/g	Sealed-gauge type: 0–100%	A.C. and d.c. measuring systems. Open and closed loop control	Scientific and industrial measurement, process control, medical, textiles, transportation. For fluids compatible with stainless steel. Frequency range given in liquid at 100 lbf/in² range. Intrinsic safety conditions up to 10,000 lbf/in² in absolute and sealed gauges
NT4–317 ★764									0·75%	0·2%	0–12 kc/s	≥50 Ω	−195 to +315°C	0·036%/degC	0·036%/degC					High temperature version of NT4–313. For fluids compatible with stainless steel. Frequency range given in liquid at 100 lbf/in² range. Intrinsic safety conditions up to 10,000 lbf/in² in absolute and sealed gauges
NT4–980 ★765	2·5×1·5 ×1·5	4 oz	Absolute	0–25 to 1000 lbf/in²	150	—	Vibrating cylinder	20% frequency variation for full scale	Calibration curve supplied	0·05%	Quasi-static	≥50 Ω	−50 to +100°C	0·02%/degC	0·02%/degC	100g	<0·001%/g	1–100%	Frequency to digital converter with 0·1% linearity being developed by manufacturers	Precise measurement of absolute pressure. Remote indication

Southern Instruments

G201 to G204 ★766	2 in long; various mounting threads	2·75 to 4 oz	Gauge	0–10 to 0-10,000 lbf/in²	None	—	Capacitance	20pF capacity-change for full scale	±1%	<1%	—	—	−250 to +300°C	1%/degC	−1% per +10 degC	—	—	—			General, engine indication, hydraulic research. For non-corrosive fluids. G201 and 203: not water cooled; G202 and 204: water-cooled
G301 and G302 ★767	1·1 a/f ×2·13 1·15× 0·875 dia	5·5 oz 1·6 oz	Gauge	0–10 to 0-10,000 lbf/in²	100	—	Inductance	2·5% inductance-change for full scale	±1%	<1%	3 kc/s (air) 13 kc/s (water)	—	Up to 150°C	0·5%/degC	0·01%/degC	—	—	—			General, engine indication, hydraulic research. For non-corrosive fluids. G301: not water-cooled; G302: water-cooled
G252	1·1 a/f	3·5 oz	Gauge	0–10 to					Calibra-tion	<1%	Flush	—	100°C	1%/degC	−1% per	—	—	—			General, engine indication, hydraulic

and G302 ★767	×2·13 1·15× 0·875 dia	1·6 oz	Gauge	to 0–10,000 lbf/in²	100	—	Inductance	ductance-change for full scale	±1%	<1%	(air) 13 kc/s (water)	—	Up to 150°C	0·5%/ degC	0·01%/ degC	—	—	—	research. For non-corrosive fluids. G301: not water-cooled; G302: water-cooled
G252 ★768	1·1 a/f ×1·13	3·5 oz	Gauge	0–10 to 0–10,000 lbf/in²					Calibration curve supplied	<1%	Flush diaphragm	—	100°C	1%/degC	−1% per +10 degC	—	—	—	General, engine indication, hydraulic research. For non-corrosive fluids. Not for use under severe conditions
G265 and G268	1·1 a/f × 5 3·37 2·13 ×	26 oz 37 oz	Gauge	0–10 to 0–10,000 lbf/in² 0–250 to 0–10,000 lbf/in²	None	—	Capacitance	20pF capacity-change for full scale	±1%	±1%	—	—	−250 to +300°C	1%/degC	−1% per +10 degC	—	—	—	Southern Instruments' d.c. system	For use in wet atmospheric conditions (protective sleeve and cable gland fitted). G268: cannot take cooling jacket
G275 ★770	1·1 a/f × 5	16 oz	Gauge	0–10 to 0–10,000 lbf/in²					±1%	±1%	—	—	−250 to +300°C	1%/degC	−1% per +10 degC	—	—	—		Measurement of small fluctuating pressures superimposed on high static pressures. Backing-off facilities. Can take water-cooling jacket. For non-corrosive fluids
G212 ★771	3·5 × 3·0 dia	14 oz	Gauge	0–1 inH_2O to 0–3 lbf/in²					Calibration curve supplied	±1%	3 c/s for 0–3 lbf/in² range	—	−250 to +300°C	1%/degC	—	—	—	—		Low pressure ranges. Can take water-cooling jacket. Type G247 for differential pressures. For non-corrosive fluids
G255 ★772	1·75 × 2·25 dia	32 oz	Differential	1–0–1 to 1000–0–1000 lbf/in²	500	Up to 1100 lbf/in²	Inductance	2·5% inductance change for full scale	<3%	<1%	—	—	−50 to +100°C	0·15%/ degC	—	—	—	—		General differential pressure measurements. For non-corrosive fluids
G207A ★773	1·75 × 0·87 dia	0·25 oz	Gauge	0–500 to 0–10,000 lbf/in²																
G207B ★774	2·25 × 0·7 dia	1·25 oz	Gauge	0–1000 to 0–10,000 lbf/in²	None	—	Strain gauge, round tube	0·1% resistance change for full scale	±1%	<1%	—	—	0–80°C	—	—	—	—	—		General. For non-corrosive fluids. Not cooled. A: small size. B: more robust than A. C: high pressure ranges
G207C ★775	2·5 × 0·825 dia	2 oz	Gauge	0–0·75 to 0–35 tonf/in²															Southern Instruments' d.c. equipment	
G243 ★776	2·87 × 1·25 dia	6 oz	Gauge	0–250 to 0–6000 lbf/in²	None	—	Strain gauge, catenary diaphragm	0·27% resistance change for full scale	±1%	<1%	0–20 kc/s	—	180°C	0·2%/ degC	—	—	—	—		Engine indication, rocketry. For non-corrosive fluids. Flush catenary diaphragm. Temperature compensation
G289 ★777	4·25 × 1·5 dia	12 oz	Gauge	0–20 to 0–1000 lbf/in²	300 to 400	—	Strain gauge, elliptic tube	0·27% resistance change for full scale	±1%	<1%	—	—	100°C	0·2%/ degC	—	—	—	—		General. For non-corrosive fluids. Not cooled. Temperature compensation ('Dean' gauge)
Teddington Aircraft Controls																				
GAE/A/ 1–199 ★778	2·345 × 1·95 dia	7 oz	Gauge, differential, absolute (air)	0–10 to 0–50 lbf/in²	20	50 lbf/in²	Potentiometer, capsules	—	±2%	±1·5%	—	Potentiometer resistance may be 1–10k Ω	−50 to +100°C	0·02%/ degC	0·04%/ degC	20g	±0·1%/g			Aircraft pressure surveys, telemetry, air density, etc. Small and light
GAE/A/ 200–399 ★779	3 × 2·63 dia	14 oz	Gauge, differential, absolute (air)	0–5 to 0–150 lbf/in²	20	150 lbf/in²	Potentiometer, capsules	—	±1·5%	±1%	—	Potentiometer resistance may be 1–10k Ω	−50 to +70°C	0·006%/ degC	0·012%/ degC	20g	±0·05%/g			Control actuation, in servo systems, Mach number indication. Good accuracy
GAE/A/ 400–599 ★780	4 × 2·57 dia	14 oz	Gauge, differential, absolute (air)	0–5 to 0–150 lbf/in²	20	150 lbf/in²	Potentiometer, capsules	—	±1%	±1%	—	Potentiometer resistance may be 1–50k Ω	−50 to +75°C	0·006%/ degC	0·012%/ degC	20g	±0·05%/g			High accuracy
GAF/A/ 1–199 ★781	1·27 × 2·75 dia	9 oz	Gauge, differential, absolute (*see note*)	0–100 to 0–600 lbf/in²	10	600 lbf/in²	Potentiometer, Bourdon tube	—	±1·5% to ±2%	±0·5% to ±1%	—	Potentiometer resistance may be 2–5k Ω	−50 to +70°C	1%/degC	±2%/ degC	10g	±0·05%/g			Gauge: air and non-corrosive liquids; differential and absolute: air only. Undamped
			Gauge	0–1000 to 0–6500 lbf/in²	10	—														
GAF/A/ 200–399 ★782	1·27 × 2·75 dia	14 oz	Gauge, differential, absolute	0–100 to 0–600 lbf/in²	10	600 lbf/in²	Potentiometer, Bourdon tube	—	±1%	±0·5%	—	Potentiometer resistance may be 2–5k Ω	−50 to +100°C	0·02%/ degC	0·04%/ degC	20g	±0·1%/g	In accordance with DTD 1085B	Measuring and recording systems	Missiles, engines. For highly corrosive fluids
GAF/A/ 400–599 ★783	1·27 × 2·75 dia	12 oz	Gauge	0–10 to 0–50 lbf/in²	20	—	Potentiometer, Bourdon tube	—	±2%	±1·5%	—	Potentiometer resistance may be 1–10k Ω	−50 to +100°C	0·02%/ degC	0·04%/ degC	20g	±0·1%/g			Hydraulic and pneumatic pressures. Non-corrosive fluids. Oil damped
GAF/A/ 600–799 ★784	1·44 × 2·1 dia	5 oz	Gauge, differential, absolute (*see note*)	0–100 to 0–600 lbf/in²	10	600 lbf/in²	Potentiometer, Bourdon tube	—	±2·5%	±0·8% to ±1·2%	—	Potentiometer resistance may be 2–5k Ω	−50 to +70°C	0·006%/ degC	0·012%/ degC	20g	±0·03%/g to ±0·05%/g			Telemetry control under severe vibrations. Gauge: air and non-corrosive liquids; differential and absolute:
			Gauge	0–1000 to 0–6500 lbf/in²	10	—														

GAF/A/ 400–599 ★783	1·27×2·75 dia	12 oz	Gauge	0–10 to 0–50 lbf/in²	20	—	meter, Bourdon tube	—	±2%	±1·5%	—	resistance may be 1–10k Ω	−50 to +100°C	0·02%/ degC	0·04%/ degC	20g	±0·1%/g				Hydraulic and pneumatic pressures. Non-corrosive fluids. Oil damped
GAF/A/ 600–799 ★784	1·44×2·1 dia	5 oz	Gauge, differential, absolute (*see note*)	0–100 to 0–600 lbf/in²	10	600 lbf/in²	Potentio-meter, Bourdon tube	—	±2·5%	±0·8% to ±1·2%	—	Potentio-meter resistance may be 2–5k Ω	−50 to +70°C	0·006%/ degC	0·012%/ degC	20g	±0·03%/g to ±0·05%/g				Telemetry control under severe vibrations. Gauge air and non-corrosive liquids; differential and absolute: air only. Undamped. Small
			Gauge	0–1000 to 0–6500 lbf/in²	10	7000 lbf/in²															
GAF/A/ 800–999 ★785	1·2×2·0 dia	8 oz	Gauge	0–1000 to 0–6000 lbf/in²	10	—	Potentio-meter, Bourdon tube	—	±1·5% to ±2%	±0·5% to ±1%	—	Potentio-meter resistance may be 2–5k Ω	−50 to +70°C	0·006%/ degC	0·012%/ degC	30g	±0·1%/g				Telemetry control under severe vibrations. Air and non-corrosive liquids. Oil damped
J. Langham Thompson																					
BP 1 ★786	5×1·3 dia	0·7 lb	Gauge	0–200 to 0–2000 lbf/in²	50	—	Strain gauge, elliptic tube	1·5mV/V output full-scale	0·5%	0·5%	0–1000 c/s	—	−40 to +120°C	0·02%/ degC	0·08%/ degC						Steady or fluctuating fluid pressures, process control, missiles, engines. For fluids compatible with chrome-molybdenum steel. Type BP2 for incremental pressures
BP 2 ★787	5·5×1·75 dia	1·5 lb	Gauge	0–200 to 0–2000 lbf/in²	50	1000 lbf/in²															
BP 3 ★788	3·25×0·93 dia	0·4 lb	Gauge	0–200 to 0–2000 lbf/in²	Up to 50	—	Strain gauge, round tube	1·5mV/V output full-scale	0·5%	0·5%	0–2000 c/s	—	−40 to +120°C	0·02%/ degC	0·04%/ degC						Steady or fluctuating fluid pressures, process control, missiles, engines. For fluids compatible with beryllium copper
BP 4 ★789	3·2×1·3 dia	0·6 lb	Gauge	0–200 to 0–2000 lbf/in²	30	—	Strain gauge, elliptic tube	1·5mV/V output full-scale	0·5%	0·5%	0–1000 c/s	—	−40 to +120°C	0·02%/ degC	0·08%/ degC	500g	0·01%/g	—	Langham Thompson RML 6019 indicator, d.c. chopper amplifier, 6-in Circscale meter		Steady or fluctuating fluid pressures, process control, missiles, engines. For corrosive fluids. Type BP5 for incremental pressures
BP 5 ★790	3·7×1·75 dia	1·4 lb	Gauge	0–200 to 0–2000 lbf/in²	30	1000 lbf/in²															
BP 6 ★791	3·25×0·93 dia	0·4 lb	Gauge	0–2000 to 0–20,000 lbf/in²	Up to 50	—	Strain gauge, round tube	1·5mV/V output full-scale	0·5%	0·5%	0–2000 c/s	—	−40 to +120°C	0·02%/ degC	0·04%/ degC						Steady or fluctuating fluid pressures, process control, missiles, engines. For corrosive fluids
UP 1 ★792	4×3 dia	1·1 lb	Gauge, differential	±10 inH₂O	300	—	Unbonded strain gauge, bellows	2mV/V output full-scale	1·5%	1·5%	—	—	−40 to +100°C	—	—	30g	6%/g	—			Steady or fluctuating fluid pressures, process control, missiles, engines. External: non-corrosive fluids; internal: dry non-conductive gases
UP 2 ★793	3·9×2·5 dia	0·8 lb	Gauge, differential	±30 inH₂O ±2 lbf/in²	400 500	—	Unbonded strain gauge, bellows	2·5mV/V output full-scale								30g	2%/g	←			
UP 3 ★794	3·3×1·625 (square flange)	0·7 lb	Gauge, differential	±5 lbf/in²	300	—	Unbonded strain gauge, bellows	2·5mV/V output full-scale								50g	1%/g	—			
UP 4 ★795	3·5×1·625 (square flange)	0·7 lb	Gauge, differential	±10 to 0–1000 lbf/in²	20 to 50	—	Unbonded strain gauge, diaphragm	2·5mV/V output full-scale	1%	1%	—	—	−40 to +100°C	—	—	100g	0·75%/g	—			
SB 2 ★796	5×2·6 dia	2 lb	Gauge, differential	0–5 to 0–20 lbf/in²	200	—	Potentio-meter, bellows	—	1 to 1·5%	1 to 1·5%	—	>100k Ω	−30 to +80°C	—	—	—	—	—			Fluid pressures, water levels, process control, aircraft, missiles. For non-corrosive fluids
PP 1 ★797	1·8×2·4 (square flange)	0·7 lb	Gauge	0–25 to 0–3000 lbf/in²	10	—	Potentio-meter, Bourdon tube	—	—	—	—	>100k Ω	−30 to +70°C	0·02%/ degC	0·04%/ degC	—	—	—	Langham Thompson PML 6009 indicator, d.c. amplifier, 6-in Circscale meter		Fluid pressures, water levels, process control, aircraft, missiles. External: non-corrosive fluids; internal: dry, non-conductive gases
PP 2 ★798	2·1×2·4 (square flange)	0·75 lb	Gauge, differential	±10 to ±20 inH₂O or ±1 to ±10 lbf/in²	50	100 lbf/in²	Potentio-meter, capsules	—	1%	1%	—	>200k Ω	−40 to +100°C	0·02%/ degC	0·04%/ degC	—	0·1%/g	—			
PP 3 ★799	2·1×2·4 (square flange)	0·75 lb	Gauge																		Fluid pressures, water levels, process control, aircraft, missiles. For non-corrosive fluids
PP 4 ★800	1·6×2·4 (square flange)	0·75 lb	Gauge	0–100 to 0–5000 lbf/in²	50	1000 lbf/in²	Potentio-meter, Bourdon tube	—	1%	1%	—	>200k Ω	−40 to +100°C	0·02%/ degC	0·04%/ degC	—	0·1%/g	—			

★ For further details circle appropriate number on reply card facing page 162

Regulating fuel oil to open-hearth furnaces

Furnace reversal while fuel flow is under auto-control

THE OPEN-HEARTH FURNACES AT THE Trafford Park, Manchester, steel-works of Taylor Brothers Ltd are fired alternately from either end, and Bailey Meters and Controls Ltd are responsible for equipment which enables the operators to reverse firing while the fuel-oil flow is under automatic control. The oil is pumped from a main storage tank, through a header, at a pressure of 180 lbf/in² gauge and at a temperature of 200°F.

The general arrangement will be apparent from Fig. 1. The rate of oil flow to a furnace is determined by the operator's manual adjustment of the desired-value setting of the flow controller. This flow controller regulates a diaphragm-operated control valve in the oil supply line to maintain the desired fuel supply. The positioner fitted to the fuel control valve has 'characterizing' cams to match it to the air signal.

Consider the reversing valve in Fig. 1 to be 'open', that is, fuel is flowing to fire the furnace from one or other end. This means that an air valve, which is operated by the action of the reversing valve, is 'closed', and the system operates in conventional fashion under the control of the fuel-oil flow loop.

While the reversing operation is taking place—the flow of fuel is being transferred from one end of the furnace to the other—the reversing valve is 'closed'. This means that the air valve is 'open' to bleed instrument air to atmosphere; pressure in one chamber of the stack relay falls, the air

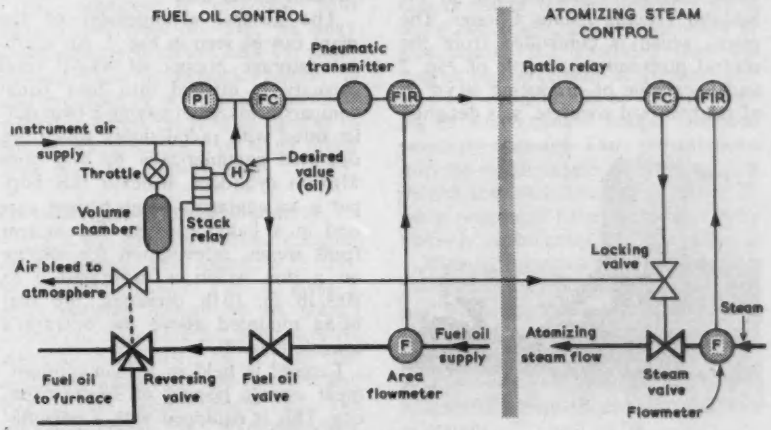


Fig. 2 Oil and steam flow control. Oil flow is controlled as in Fig. 1. Atomizing steam flows during reversal because, when the air-bleed valve opens and air pressure drops, a locking valve closes to lock the steam valve in position. When reversal is complete and the air valve closes, the locking valve opens and control proceeds normally

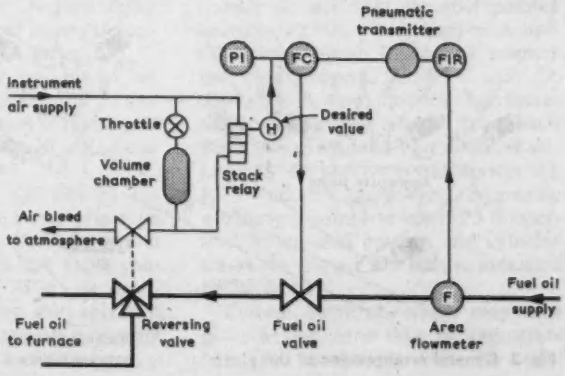


Fig. 1 Fuel-oil flow control. During furnace reversal, the reversing valve closes, opening an air-bleed valve and so cutting off the air supply to the control system, and closing the fuel-oil valve. When reversal is complete, the air valve closes and the air pressure rises, making the oil-flow control loop operative again

supply to the control system is shut off, and the fuel-oil control valve closes.

When reversal is complete and the next firing half-cycle begins, the reversing valve opens, and the air valve closes so that the air pressure builds up at a rate dependent upon the adjustment of the throttle. As this pressure increases, the pressure in one chamber of the stack relay rises, and a steadily increasing desired-value signal is fed to the fuel-flow controller. The latter thus regulates the opening of the diaphragm-operated fuel-control valve

so that it opens slowly. Furnace 'puffs', which can occur when firing is commenced too rapidly after a reversal, are thus avoided.

Fuel and steam control

At Taylor Brothers it is also required that the flow of steam to the atomizing burners should be controlled, and Bailey Meters are now installing equipment to do this. The intention is to control the atomizing steam flow so that six pounds of steam is supplied for every gallon of fuel oil. The system operates in conjunction with the fuel-oil control, described above, and is shown diagrammatically in Fig. 2.

Both oil and steam flow are controlled, the oil-flow signal being proportioned to form the desired-value signal to the steam-flow controller which positions the atomizing-steam valve. It is necessary that the atomizing steam should continue to flow during the reversing operation, and at the same rate of flow as that immediately prior to reversal. This is achieved with the aid of an air-operated locking valve which is connected in the output of the positioner of the steam-control valve.

The supply from the air valve, which is operated by the action of the fuel-oil reversing valve, is cut off during furnace reversal, in the manner described above. This causes the air locking valve (or 'fail-fix' valve) to close, locking the position of the steam control valve and so maintaining the flow of atomizing steam. Once reversal is complete, the air valve closes and the air supply increases, so opening the locking valve and allowing the control system to operate normally.

CONTROL IN ACTION

Concrete produced automatically

Ready-mixed concrete under electropneumatic control

A SINGLE OPERATOR CONTROLS AN automatic concrete batching and mixing plant which is now operated by John Henshall (Quarries) Ltd at the Sealand Trading Estate, Chester. The plant, which is controlled from the central push-button console of Fig. 2 and is capable of producing 60 yd^3/h of ready-mixed concrete, was designed and manufactured by Millars' Machinery Co. Ltd, electropneumatic control being the responsibility of Maxam Power Ltd.

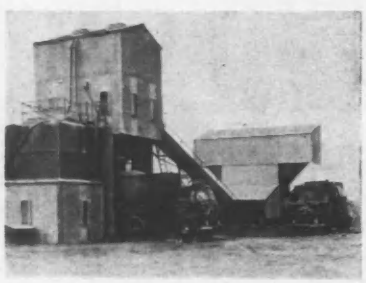


Fig. 1 John Henshall's automatic concrete batching plant

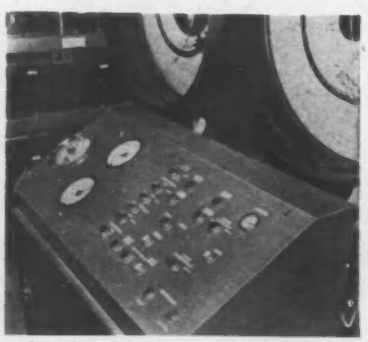


Fig. 2 The weight-indicating dials and console are grouped together for control by a single operator

The general arrangement of the plant can be seen in Fig. 3. An aggregate storage hopper of 48 yd^3 total capacity is divided into four equal compartments, each having a twin outlet fitted with radial doors which are operated pneumatically by 4-in bore Maxam cylinders. Beneath this hopper is an aggregate-weigh hopper carried in a batch-weigher. The system feeds weight information for display on a dial which is calibrated 0 to 8000 lb in 10 lb divisions, the dial being mounted above the operator's console (Fig. 2).

Cement is held in a twin-compartment storage hopper of 30 cwt capacity. This is equipped with a pneumatic conveyor and blowing unit for charging a cement surge hopper of 10-ton capacity, which has twin compartments. Beneath the surge hopper is a cement-weigh hopper, carried in a batch-weigher, which is connected to a remote dial calibrated 0 to 1500 lb in 5 lb divisions, and also situated above the operator's console. The outlet of the weigher is fitted with reverse radial-type doors operated pneumatically by 3-in bore cylinders.

Before commencing the production cycle, the operator positions transistorized photo-electric scanning heads, which are sited on a ring immediately in front of the weigh dials, in order to obtain the required weight of aggregate and cement from each storage hopper. The operator then presses a 'start' button for aggregate and cement weighing, both materials being

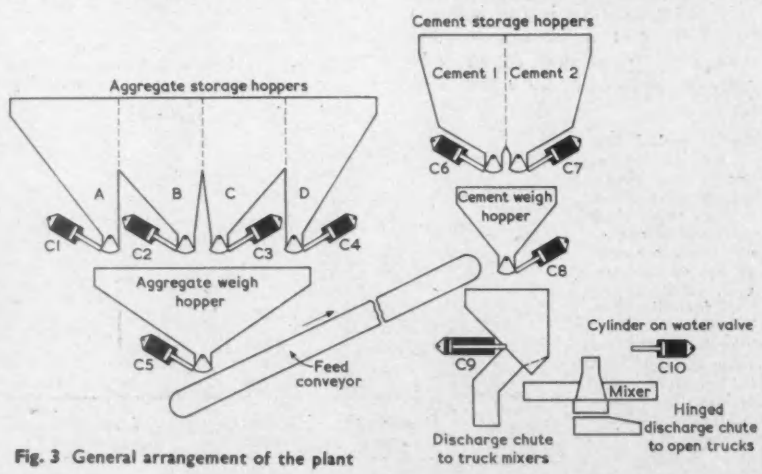


Fig. 3 General arrangement of the plant

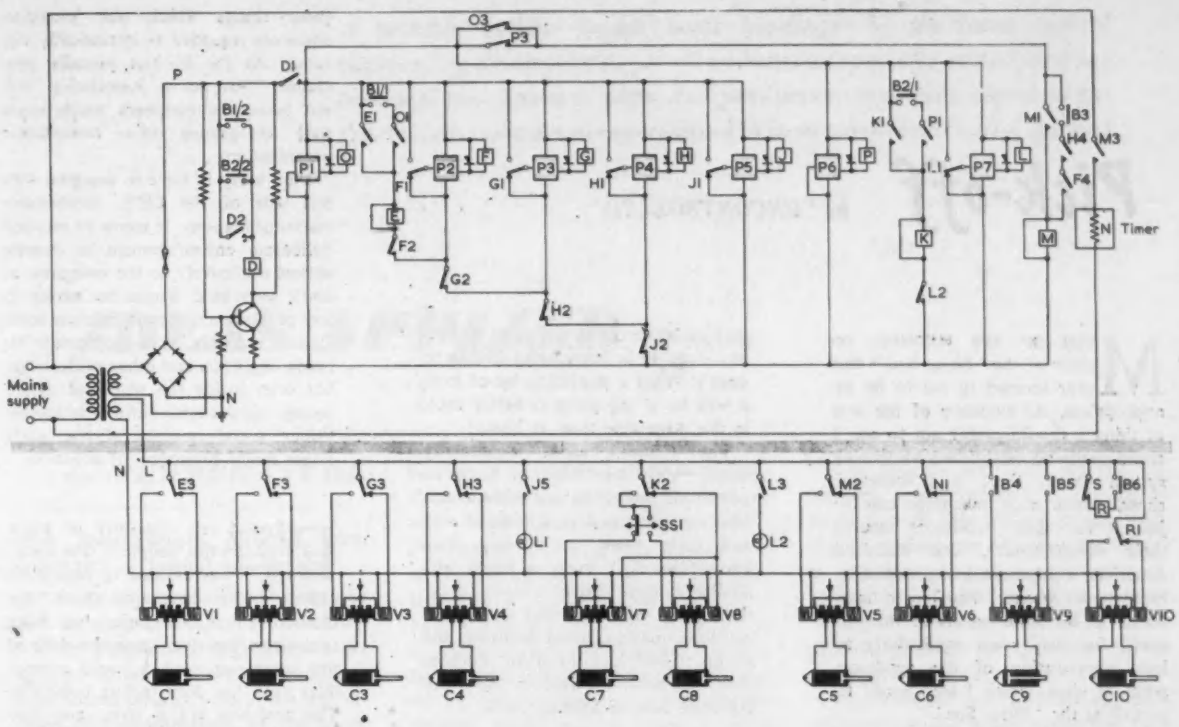


Fig. 4 Circuit diagram showing push-button switches, photo-electric scanning devices (P1 to P7) on the weigh dials, and solenoid-operated pneumatic cylinders which control the feed of materials. (Manual override control not shown)

weighed simultaneously. The respective doors open and materials discharge into the weigh hopper. As the weight-recording pointers of the dial indicators move in response to weight signals, they pass the pre-positioned photo-cells causing electrical impulses to be fed to the solenoid valves which operate the cylinders. The aggregate doors open and close in succession, and lights on the control platform indicate when the weighing of both materials is complete. The 'unload for mixing' button is then operated and the aggregate is discharged onto an inclined troughed-belt conveyor, 84 ft long, which feeds into a 1½-yd³ compulsory paddle mixer. A time delay ensures that cement and aggregate discharge together into the mixer.

The Millars' mixer has blades on twin shafts, and is driven by a 50 h.p. Crompton Parkinson motor running at 1500–1440 rev/min through a Radicon reduction gear-box.

Water is added to the mix by the operator, the amount being preset on a Tyler water meter. A Maxam 3-in bore cylinder operates the valve controlling the flow of water, its opening being initiated by the operator, and this closes automatically on receipt of a signal from the water meter.

The operator is provided with manual overrides so that he may weigh directly from the scale for small batches. Electropneumatic control is also provided in the cement conveyor system to divert the flow of cement to one or other of the silos when filling them from the blowing unit.

Photo-electric-pneumatic control

Fig. 4 is a simplified circuit diagram of the system, and reference to this, in conjunction with Fig. 3, gives a more detailed picture of the plant's operation. There are five photo-electric scanning heads (P1 to P5) on the aggregate-weigh dial and two (P6 and P7) on the cement-weigh dial. The operator pushes the 'start aggregate weighing' button, B1, and, provided that P1 is operated by the dial pointer, cylinder C1 opens hopper A. When the weight of aggregate in the weigh hopper is such that the dial pointer operates P2, C1 closes hopper A and C2 opens hopper B. In this manner the four hoppers, A, B, C and D, discharge in turn into the aggregate-weigh hopper, the amount from each being predetermined by the initial settings of the photo-electric devices P2, P3, P4 and P5, respectively. Aggregate weighing is complete when P5 is operated by the dial pointer, and cylinder C4 closes hopper D. This is indicated by lamp L1.

Cement batching, which may take place at the same time as aggregate batching, commences with the selection of either cement hopper 1 or 2, using switch SS1, and the operation of push-button B2. Provided that the pointer on the cement-weigh dial operates P6, cylinder C6 or C7—depending on which cement hopper has been selected—operates. Thus cement flows into the weigh hopper until the pointer on the cement-weigh dial operates P7, when weighing of that material is complete, as is indicated by lamp L2.

If it is intended to load the two materials into truck mixers, push-button B4 is operated; if they are to be discharged with water into the mixer on the plant, B5 is operated. These switches control cylinder C9, which will move a flap to give the required selection.

For discharge to truck mixers, B4 is operated and cylinder C5 acts, allowing the weighed aggregate to be discharged onto the feed conveyor. After a time delay sufficient to allow the aggregate to reach the top of the conveyor, cylinder C8 on the cement-weigh hopper operates, and both aggregate and cement are fed together to the truck mixers.

For the supply of ready-mixed concrete to open trucks, B6 is operated and the system proceeds much as before, although cylinder C9 is now acting to divert the flow of material to the mixer, which also receives water. After a predetermined amount of water has passed into the mixer, cylinder C10 closes the water valve, and mixing proceeds.

Pick-off

by 'UNCONTROLLED'

MUCH OF THE MATERIAL on show at the 'Phys. Soc.'* this year seemed to me to be inappropriate. As evidence of the sort of thing I should prefer not to see, I could quote an established computing system (surely there is a computer show, where such machines can be judged for their excellence against their competitors?), and standard American equipment being manufactured under licence. The larger firms seems to be most remiss in this respect, for they seem particularly to lack appreciation of the academic point of view, which I feed ought to prevail at the 'Phys. Soc.'.

Less alarming, but perhaps more surprising, was the lack of knowledge displayed this year by some of the exhibitors' representatives. I followed the exhibition from the catalogue (an extremely useful publication for which, in general, the organizers deserve praise). One representative, set to guard a single exhibit which, for him, was clearly the *raison d'être* of the whole show, calmly assured me that it represented two manifestly different catalogue items; he even went so far as to explain, in a brief ecstasy of confusion, how this remarkable transformation could be brought about. Another, confronted with a particular catalogue entry, took the attitude that as he knew nothing of it, the catalogue must be in error; he showed no inclination to consult any of his numerous colleagues on the question. Personally, I liked best the more straightforward form of legerdemain practised by yet another exhibitor, who started one item of his catalogue entry with the words 'On show for the first time will be the . . .' and ended it with the remark, in parenthesis, 'Will not be on show'.

I HEAR THAT the Argentinian Centre for Automatic Control was so impressed by Dr Foster's 'Viewpoint' in last July's *Control* that it has asked for the Editor's permission to circulate the text locally. Dr Foster (you may remember) was telling us to buck our ideas up in automating British industry. What a punishing bit of irony it will be if the point is better taken in the Argentine than at home!

The Centre's aims, incidentally, seem wholly laudable: to bring together all 'scientists and technicians' who are interested in automatic control, help them to improve their knowledge of it, keep in touch with similar bodies abroad, foster education, study economic and technological consequences, assist industry, and so on. Good luck to them. Perhaps they will soon be able to show our B.C.A.C. how to activate itself.

TWO PROBLEMS concerned with technical graduates seem constantly to preoccupy the minds of those whose business it is to consider such matters: one is how to get enough of them, and the other is what to do with them when you have them. A recent publication, inspired by the Institution of Electrical Engineers and entitled 'The Training of Graduates in Industry', deals with the second problem.

One rather surprising aspect of the publication, I thought, was that the committee which produced it considers it a duty to organize the graduate's leisure, as well as his working hours. Surely a graduate, having had (one assumes) the major responsibility in planning the use of his time during his university career, can at least organize his own leisure hours on returning to the outside world? The graduate, I feel, may justifiably be offended at the degree of control which the I.E.E. committee considers it fitting to exercise over his spare time. Not only do they think that the trainee requires 'guidance . . . on his private reading', but that an association should be formed to 'co-ordinate the appropriate activities of all apprentices outside working hours'. Although 'appropriate activities' are not specifically defined, the ones enumerated in the following paragraph include cycling, youth-hostelling, and cricket—in fact all those things which our Victorian ancestors regarded as intrinsically virtuous. As the booklet proudly proclaims, 'An active Association will not leave the members much spare time for joining other recreational organizations . . .'.

I am sorry to have to disagree with this side of the I.E.E. committee's recommendations. It seems to me that deliberate encouragement to remain almost exclusively to the company of one's own kind would be wrong in any profession. Already barriers seem to exist, not only in communication between engineers and other professions, but even inside the world of engineering, between its various branches. Wider social contact at the early stages might improve this situation.

ENJOYING THE COMPANY of some medium-top people a few weeks ago, I was amused to hear their rather fruity language about the Government. 'Electronics has been sold down the river' was the drift of the complaint, and I could sympathize with the deep feeling behind it. The cost-plus era is over, and free enterprise is not suiting everybody. It is interesting, and perhaps instructive, that the deserted industries are looking for their salvation in the automatic control business. The home market is alarmingly small, however, and I fear that many firms are in for a thin time. It would be another story if the trade barriers could be wiped away in Europe, but six plus seven seems to make an unlucky number.

TALKING of the top people again, how do they get enough feel of the contemporary technical situation to make sensible and profitable decisions? In other countries, on both sides of the Atlantic, the most senior men meet at professional conferences and exhibitions, not only to hear what their peers will let out, but to discover how the other half lives—the other half in the lower levels of the industrial pyramid. In this country we seldom see apex-men at professional meetings. Last month's informal gathering at the Institution of Mechanical Engineers,* for instance, was attended mainly by young technologists, and the senior men there were not (on the whole) in the loftiest managerial class. I thought this was a shame, because the managers ought to learn a lot from this kind of meeting. Is it false dignity that keeps the policy-makers out of sight? Their decisions look no better, for all that.

*Reviewed this month on p. 85—EDITOR

*Reported this month on p. 88—EDITOR

A monthly review—under basic headings—of the latest control engineering developments for all industries; specially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are not specialized in instrument and control systems

IDEAS APPLIED . . .

. . . to TEMPERATURE

High temperatures inferred from properties of heated gas-stream

The method of measurement described here is being developed by Constructors John Brown for high-temperature applications where thermocouples have been found unsatisfactory, mainly because of contamination of the wires. Basically, the method depends on the variation with temperature of the pressure drop in an inert gas flowing through a capillary at a constant rate. A 'measuring' capillary is built into a probe which is at the temperature that is to be measured; the pressure drop across this capillary is compared in a bridge network with the drop across another capillary which is kept at constant temperature. The apparatus is designed so that it can, if necessary, be made entirely of non-metallic refractory materials.

The arrangement of the 'gas-bridge thermometer' is shown in Fig. 1.1. A filtered supply of low-pressure inert gas enters the bridge at *E*. The gas passes through the bridge by one of the alternative routes *BA* and *CDF*; *A*, *B*, *C* and *D* are capillary restrictions. Any pressure difference between the *B*-*A* 'junction' and the *C*-*D* 'junction' is indicated by the manometer *M* (or other pressure-measuring device). An obvious advantage of this arrangement is that only clean, inert gas passes through the measuring device; the system is, in fact, being continuously purged.

For a gas flowing through a capillary, the pressure drop across the capillary is proportional to $l\mu u/\rho d^4$, where l = capillary length, d = diameter, μ = gas viscosity, ρ = density, and u = mass flow. If the gas were perfect, ρ would be inversely proportional to the absolute temperature, T, and μ would be proportional to $\sqrt{T}$. Neglecting the changes in d and l due to the change in T, p will be proportional to $T^{3/2}$ if the mass flow, u, is kept constant. Thus variations of p, as indicated on the manometer, may be expected to give a good indication of T. For real gases, p usually increases more rapidly with T than would be expected from this law.

For optimum sensitivity, it is desirable that the bridge should operate in an approximately balanced condition. Clearly this can occur at only one temperature, so that the bridge will normally be designed to balance at a convenient point in the working range. This is achieved by making all capillaries of the same diameter, but altering the length of *B* so that the pressure-drops across *A* and *B* are equal at the chosen 'balance' temperature. Reference to the expression given above for the pressure-drop across a capillary shows that the lengths require to be such that $l_A/l_B = (T_B/T_A)^{3/2}$ where T is the absolute temperature, and the suffixes *A* and *B* refer to the appropriate capillaries.

The arrangement is closely analogous to an electrical Wheatstone bridge, the manometer, which corresponds to the galvanometer, showing any departure from the balance condition. The tube *F* is analogous to the compensating leads employed when a Wheatstone bridge is used as a temperature measuring device with a resistance thermometer element. When the bridge is balanced, the gas-flows in the two probe tubes are identical, as are the temperature gradients along them. Consequently the pressure-drops along these two tubes will be equal, and no error will be introduced.

The balance condition will be unaffected by the pressure of the supply at *E*, though this will affect the reading of manometer *M* when the bridge is unbalanced, and consequently requires to be stabilized by a pressure regulator. The manometer *N* is included to check the operation of the regulator.

The flow of gas through capillary *A* tends to cool it and cause low temperature readings. This effect can be minimized by keeping the gas flow small, and by ensuring that an ample length of probe upstream of *A* is heated to the temperature to be measured. The residual effect can be allowed for in calibration.

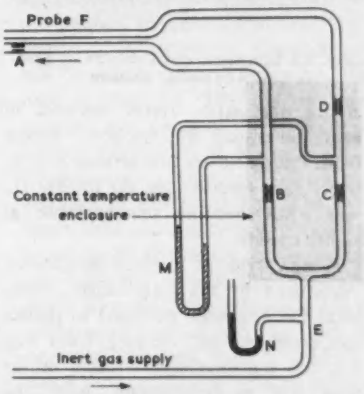


Fig. 1.1 General arrangement of gas-bridge thermometer

An experimental bridge of this type has been tested for a 100-h period at temperatures between 1000°C and 1200°C. No drift was observed during this period, and overall accuracy, referred to a platinum/platinum-rhodium thermocouple, was within ± ½%. The test apparatus incorporated certain refinements not shown in Fig. 1.1, including a connexion between the open end of the manometer *N* and the

furnace; this made it possible to regulate the supply pressure with respect to the furnace pressure, rather than with respect to atmospheric pressure. Sensitivity of the equipment was of the order of 0·5 in H_2O/100 degC, but it is pointed out that the design could be modified to give much greater sensitivities. Further tests at temperatures of about 1600°C are contemplated.

The whole equipment is the subject of provisional patents taken out by Constructors John Brown.

Pyrometer for moving surfaces

The temperatures of moving surfaces, such as those of high-speed cylinders used in the paper industry, are conventionally measured by thermocouples fabricated from flat strip. These are applied directly to the surface, and

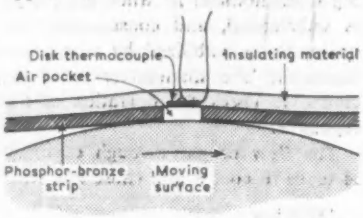


Fig. 1.2 Schematic cross-section of pyrometer sensing element

errors necessarily result because of heat generated by friction. Errors from this cause are not serious at relatively low speeds—say up to 200 ft/min—but become unacceptable at higher speeds.

A new type of surface pyrometer, introduced by the Cambridge Instrument Co, has been designed to reduce this error. As will be seen from Fig. 1.2, the thermocouple in this device does not make contact with the moving surface, but forms one face of a shallow cylindrical air cavity. The opposite face of this cavity is formed by the moving surface. In operation, the flexible phosphor-bronze strip, in which the air cavity is cut, is brought into contact with the surface; the enclosed air becomes turbulent and quickly reaches a temperature corresponding to that of the surface; this temperature is detected by the disk-type thermocouple, which, being heavily insulated on its upper side, also follows the surface temperature.

The air pocket in this design is 0·03 in deep. The thermocouple comprises a copper disk with a constantan lead soldered to its centre, and a copper lead soldered to its periphery, the disk being held in place by a Silastomer moulding. This material, which is flexible, and has good heat-resisting properties, is bonded to the phosphor-bronze strip and reinforced with fibreglass.

It is thought that this pyrometer will be suitable for use at surface speeds of up to at least 2000 ft/min and temperatures up to about 300°C. Tests carried out by the makers suggest that the response time (to reach 99% of the final reading) is about 1¼ min and that the total error at 100°C will not exceed ± 2 degC.

. . . to SERVO-MOTORS

Modular construction of gear-heads giving wide range of gear-ratios

M. D. HULL, *Pioneer Designs Ltd.*

Standard gear-heads for miniature servo-motors are usually supplied with reduction ratios of 40, 80, 150, 300 or 600:1. To obtain higher ratios these gear-heads may be used in cascade, other ratios being achieved by specially made gear-heads. There remains, however, a demand for a relatively inexpensive means of obtaining a wide range of gear-ratio.

A system being developed by the Servokits Division of Pioneer Designs Ltd is intended to satisfy this demand. Gear-heads are built up of a series of modules, each containing a mating gear and pinion, stacked on end until the desired ratio is reached, as shown in Fig. 2.1. The design is so rationalized that a minimum number of different component parts is used. The system produces a wide variety of gear-ratios, e.g., 33 different ratios between 1:1 and 100:1 may be obtained with a size-23 gear-head. Standardization of the component parts results in considerable reduction in final cost.

The basic approach in the design of these gear-heads has been to use a fixed centre-distance for all mating gear-and-pinion pairs in a gear-head of given international frame size. This permits the bearing plates to be standardized for each size. Mating pairs are made in a series of whole-number ratios, i.e., 2:1, 3:1, 4:1, and so on, using pinions of 21 teeth in each case. To achieve this in conjunction with the fixed centre-distance, it is necessary to use a different diametral pitch (d.p.) for each ratio.*

The reduction which can be achieved in one pass is limited by (i) the minimum size of the pinion and (ii) the gear-head frame size. Clearly there is a lower practical limit to both the number of teeth on the pinion and to the size of tooth (i.e., when the number of teeth has been fixed, a maximum limit on the d.p.). When the minimum pinion size has been thus decided, the maximum reduction at one pass is determined by the physical limitation, imposed by the frame size, on the diameter of the mating gear.

For international frame sizes 11, 15 and 18, the standard servo-motor output pinion has 21 teeth of 120 d.p. This pinion was taken as the standard size for the system under discussion. The standard centre-distance for each frame size was then defined as that obtained when mating this pinion with the largest possible gear (within the limits imposed by the frame diameter). Thus, for a size-23 gear-head, the largest whole-number ratio obtainable in this way is 5:1, using a 105-tooth 120-d.p. gear. The centre-distance for this pair is 0·525 in. This distance is taken as standard for the size-23 gear-head, and the appropriate d.p.'s are calculated for mating

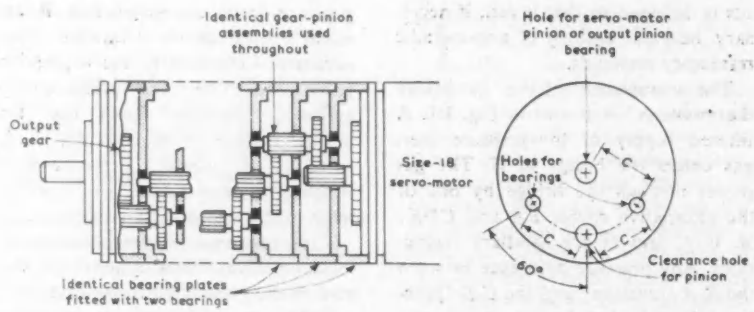


Fig. 2.1 Construction of typical gear-head. Left: schematic section. Right: bearing-plate layout

* The diametral pitch (d.p.) of a gear is the number of teeth divided by its pitch circle diameter. If two mating gears are to give a ratio of r:1, and the number of teeth on the smaller gear (pinion) is n, it is easily seen that the d.p. is related to the centre-distance c by the formula d.p. $= n(1 + r)/2c$. In the system described here, n and c are fixed for a given gear-head, necessitating a change of d.p. whenever r is changed.

pairs, to give the lower whole-number ratios of 4:1, 3:1, and 2:1.

It is desirable with this system that the required overall gear-ratio should be obtained by using a series of passes of the same reduction, thus allowing use of a series of identical gear-and-pinion assemblies. The method of construction (Fig. 2.1) is designed so that each gear-pinion assembly is of equal length, and the distance between the gear and pinion on the assembly is constant. All gear-pinion assemblies will thus be identical if the reduction at each pass is the same, but if this reduction is not constant, a non-standard assembly having gear and pinion of unequal d.p. will have to be included. Only the servo-motor pinion which drives the gear-head is coaxial with the output gear on the axis of the gearhead. The centres of the gear-pinion assemblies are successively orientated at 60° intervals around this axis. Theoretically any number of modules can be stacked in the manner shown, correct alignment being ensured by dowels.

. . . to DATA HANDLING

Analogue-to-digital converter for high-speed scanning system

In digital data handling systems where the input information is taken from large numbers of d.c. low-level analogue sources, two problems of signal amplification usually arise. Firstly, a decision has to be made on the number of amplifiers, i.e. whether to have individual amplifiers for each source, or to arrange for a number of sources to share one amplifier; the latter arrangement is more economical, but introduces further difficulties associated with the switching of low-level signals. Secondly, if amplifiers are used in the conventional manner, it is difficult to obtain the stable and linear gain characteristic necessary for high accuracy.

A new approach to these amplification problems is seen in a system developed by Marconi Instruments for temperature scanning in nuclear power plants. Signals are switched at low-level by dry-reed relays, and analogue-to-digital conversion is carried out without amplification in the conventional sense.

The dry-reed relay comprises two flexible contact-strips of ferro-magnetic material, sealed inside a glass tube and controlled by an external coil. The strips are fixed in opposite ends of the tube, with their free ends overlapping to form contacts. Good contact is ensured by plating the contact area with gold or other precious metal; the tube is filled with inert gas, and completely sealed.

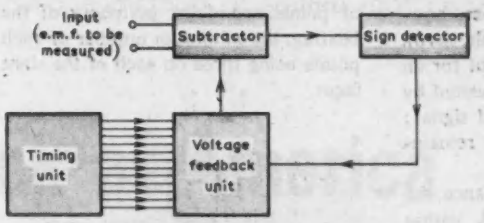


Fig. 3.1 Block diagram of digitizer. The voltage feedback unit responds with a series of potentials to impulses from the timing unit; the subtractor compares these potentials with the input

This method of switching has been shown to perform well over 10^8 operations in this application, and should be free from 'noise' and dirty-contact troubles. Speed of operation is of the order of 1 ms in either direction.

The four main elements of the analogue-to-digital conversion equipment are shown in simplified block-schematic form in Fig. 3.1. The timing unit sequentially energizes a number of lines which control the various operations of the system. At any given time in the sequence, the voltage feedback unit generates a specific voltage which is compared with the voltage to be measured. The difference between the two voltages is fed to the sign detector, which sends a signal back to the voltage feedback unit. This signal depends only on the sign of the difference, and not on its magnitude.

The sequence of operations is as follows. The first signal sent to the subtractor produces a voltage corresponding to a temperature of 512°C. This is compared with the unknown voltage, and either an 'above' or 'below' signal is returned to the voltage feedback unit. If a 'below' signal is received (i.e. the unknown voltage is the lower), the next output signal corresponds to 256°C; an 'above' signal results in an output made up of the sum of the original output and the 256°C signal, i.e. a signal representing 768°C. This process is repeated eleven times for each complete measurement; after each comparison, the previous feedback signal remains 'on' if the unknown voltage was the higher, and is taken 'off' if it was the lower. When one such measuring sequence is completed, the final state of the switching for the feedback signals (i.e. 'on' or 'off' for the 512°C, 256°C, 128°C . . . signals in order) gives a binary-coded digital signal representing the thermocouple output to the nearest ½ deg C.

The electronic circuits used in this system are described elsewhere (*1*), and will not be given here. However, the method of comparison and digitization is of interest in principle, and can be seen in general terms by reference to Fig. 3.2. The outputs being scanned are switched in turn to the input terminals (*I*, *I*) of the digitizer. *D* represents a stabilized voltage supply unit in which the line *A* is at all times held accurately 6 V positive relative to *B*; the line *A*, however, cannot pass any appreciable current in either direction. The resistance *r* is the 'subtractor' of Fig. 3.1, and the potential between lines *C* and *A* is equal to the voltage generated across *r*.

The timing unit closes each of the switches $S_1 \ldots\ldots S_{11}$ (actually transistor circuits) in turn. When S_1 is closed, a current of $6/R_1$ amps flows from *B* through R_1 and *r* to *C*. This current causes a voltage drop of $6r/R_1$ across *r* (corresponding to a measured temperature of 512°C) in opposition to

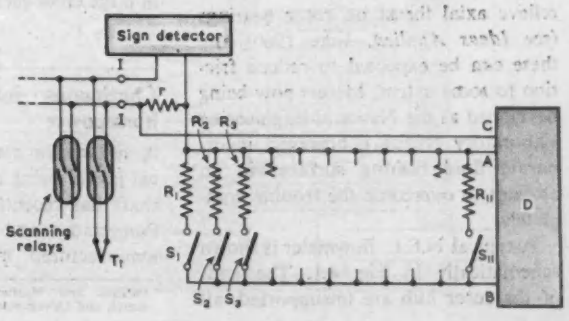


Fig. 3.2 Schematic diagram of voltage feedback unit. The switches $S_1 \ldots\ldots S_{11}$ represent transistor switching circuits, and r is the subtractor of Fig. 3.1

the output from the thermocouple. The direction of the resultant potential across the input to the sign detector thus depends on the relative magnitudes of the thermocouple input and the feedback input across *r*.

The sign detector is a d.c. amplifier, but because of the manner in which it is used, it does not require to have stable or linear gain. (It does, however, require to have a stable zero). This amplifier gives full output for an input smaller than that represented by the final digit of the digitized signal; for higher inputs, the output remains saturated.

It may be noted that, at balance, the thermocouple e.m.f. is equal, within one digit, to the voltage across *r*, so that the effective input impedance is much higher than the input impedance of the sign detector; this means that the thermocouple impedance may be high without affecting the reading.

The system has been designed for an accuracy of 0·1% of full-scale reading, and for a conversion time of 25 ms. Circuits can be incorporated to linearize the outputs of copper-constantan and chromel-alumel thermocouples, so that the digitized output is directly representative of temperature rather than thermocouple e.m.f.

References

1. Gilbert, R. L. G.: 'An Analogue-Digital Converter with Long Life' *Journal Brit. I.R.E.*, 1960, 20 (No. 7, July), pp. 529-535

. . . to FLOW

Meter with fluid rotor-bearing surface

Flowmeters incorporating a 'propeller'-type rotor driven by the metered fluid appear to be becoming increasingly popular, possibly because of the ease with which the output from such meters may be obtained in digital form. Meters of this type tend to be inaccurate at low flows. A major cause of this inaccuracy is bearing friction, which varies in an indeterminate manner. Various means have been adopted on commercial flowmeters to relieve axial thrust on rotor bearings (see *Ideas Applied*, June 1960) and these can be expected to reduce friction to some extent. Meters now being developed at the National Engineering Laboratory (N.E.L.), however, incorporate fluid bearing surfaces in an attempt to overcome the trouble completely.

A typical N.E.L. flowmeter is shown schematically in Fig. 4.1. The ends of the rotor hub are unsupported, all bearing loads being taken on the slant surfaces of a bearing ring which surrounds the rotor. The space between these bearing surfaces and the corresponding stationary surfaces is continuously supplied with high-pressure fluid, this fluid being identical with that being metered. The high-pressure fluid is supplied through ports at a number of points round the periphery of the bearing, the minimum number of such points being three on each of the slant faces.

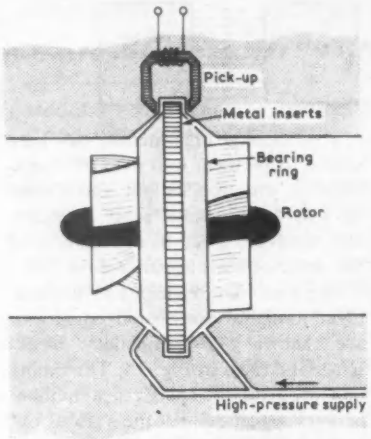


Fig. 4.1 N.E.L. rotary-type flowmeter with fluid-film bearing (schematic)

Output is obtained from an electromagnetic pick-up in the usual way, pulses being produced by the movement of metallic inserts in the plastic bearing ring.

This method of using a dynamic fluid film between the static and rotating parts eliminates all static friction. It permits a wider range of flows to be metered with a linear response than is possible when conventional bearings are used. The N.E.L. hopes that it will be possible to mould rotors with sufficient accuracy to make individual calibration unnecessary. The prototype was designed for fitting in a pipe, but it is thought that the method will also prove useful for point measurements in large cross-sections.

. . . to POWER

Continuous integration of shaft horsepower

A system for measuring the mechanical power being delivered by a driving shaft has recently been developed by Pametrada* and is being applied and manufactured by Muirhead & Co. The system, shown schematically in Fig. 5.1, gives a digital indication of the work done—in horsepower-hours—by a ship's propeller shaft.

The torque in the shaft is inferred from the angular strain. Two identical armature rings, have typically eleven poles, are fixed at a known distance apart on the driving shaft. As the shaft rotates, pulses are generated by the electromagnetic pick-ups *A* and *B* as a result of the movement of the armature poles. The armature rings are accurately aligned so that, when no torque is applied to the shaft, the pulses from *A* and *B* occur simultaneously. When torque is applied, the shaft twists and the *B* pulse lags the *A* pulse by an amount proportional to torque.

A generator, which is driven from the main shaft, produces an a.c. signal of frequency proportional to shaft speed. This a.c. signal is fed to an electronic 'gate' which is opened by the *A* pulse and closed by the *B* pulse.

Since the interval between the pulses from *A* and *B* is proportional to torque, the number of a.c. cycles which is allowed to pass through the gate is proportional to the work done. These a.c. signals are used to operate a counter, which therefore indicates the total work done over a given period.

At any given time, mean shaft horsepower may be obtained by taking a separate output from the counter and

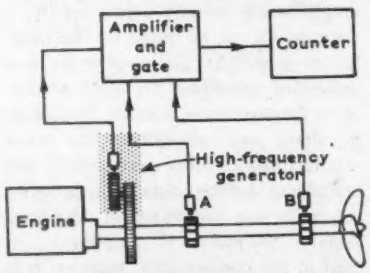


Fig. 5.1 Schematic diagram of power measuring system

feeding it to another counter for a short fixed period. Similarly, mean shaft speed is obtained by counting the pulses from *A* (or *B*) over the same period.

This equipment was developed to make efficiency figures obtainable during the normal operation of the ship, or during acceptance tests. It is claimed that accuracy at normal speeds should be within 0·25%, provided that the torque/strain relationship for the shaft is accurately known.

* Parsons and Marine Engineering Turbine Research and Development Association.

Included in this month's news-letter from our American correspondents is a description of a flowmeter incorporating a unique method of square root correction

Look at America

This month: numerical control—root-corrected flowmeter—telephones—servo compensation—education

Pneumatic-hydraulic numerical control

A recent and unique advance in numerical control has been the development of a pneumatic-hydraulic point-to-point positioning system by Moog Servocontrols, Inc. East Aurora, New York (*1*,*2*). The new Moog system employs only pneumatic and hydraulic circuitry from the tape reader to the *X* and *Y* axis machine-table actuators. Binary-coded information on a standard 1-in, eight-channel punched tape is read by a pneumatic tape reader. Information from the reader, in the form of air pressures, serves to operate a multi-level binary selector valve that in turn defines the desired position of a hydraulic controller.

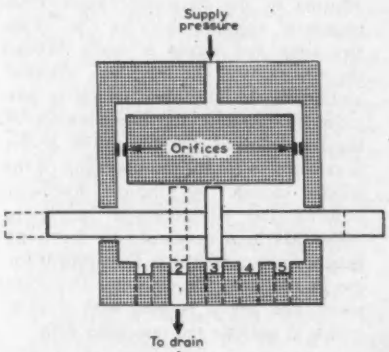


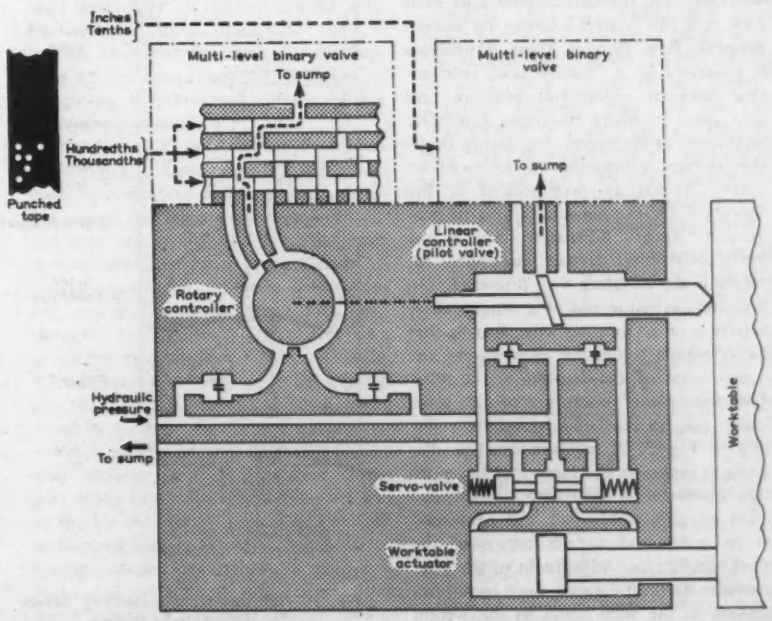
Fig. 1 Cross-section of linear hydraulic controller, showing 'hole-seeking' characteristic

The principle of operation of the hydraulic controller is best understood by referring to Fig. 1. If, for example, No. 2 hole in the cylinder wall is opened to drain, the pressure in the left end of the cylinder will drop. The resulting pressure difference will cause the piston to move to a 'null' position over the hole so that the leakages to drain and the pressures on either side of the piston are balanced. The controller becomes a numerical positioner if provision is made to select any one of a series of holes in the cylinder as a result of commands from the punched tape. The positional accuracy of the controller, operating under no load, is determined by the accuracy of location of the holes, whereas the resolution is governed by the number of holes. Naturally, practical limitations to the number of holes per unit length do exist.

In order to achieve numerical positioning in increments of 0·001 in while still maintaining a reasonable degree of simplicity, the actual system shown schematically in Fig. 2 employs a 'two-stage' hole-seeking controller. The 'two-stage' device combines a rotary and a linear version of the hole seeking controller of Fig. 1.

The linear controller has ten holes per inch in the cylinder wall, thereby allowing positioning in 0·1 in increments. Information from the inches and tenths digits coded on the punched tape is supplied to a multi-level binary selector valve which then selects the proper drain hole. A rotary version of the same controller is used to provide rotary motion of the linear piston. The linear piston has a helical land so that if the piston is rotated, axial motion results in order to maintain a 'null' position over the drain hole. Information from the

Fig. 2 Schematic diagram of hydraulic-pneumatic numerical control system



hundredths and thousandths digits coded on the punched tape operates a multi-level binary selector valve which defines the position of the rotary hole-seeking controller.

Work-table positioning accuracy ideally would depend on the accuracy of location of the drain holes in both rotary and linear controllers. However, this ideal situation assumes that loading of the linear controller, should it be used to control the work-table position directly, has no effect on static accuracy. Unfortunately, this is not typically the case. To ensure that static accuracy is maintained, the linear controller is used instead as the pilot stage for a conventional four-way servo-valve which in turn controls the flow of hydraulic fluid to the machine-table actuator. Whenever the linear controller (or now the pilot valve) has not assumed a null position over a particular drain hole, a differential pressure is developed to operate the servo-valve. Resulting motion of the machine table is sensed by the pilot valve, and as soon as the desired work-table position is reached, equal pressures will exist across the valve. A differential area on the pilot valve piston provides a net force tending always to hold the piston rod against the machine table. The system, as shown in Fig. 2, is claimed to have a positional accuracy of ± 0·0005 in and a positional repeatability within ± 0·0003 in.

Vibrating-wire flowmeter

For years, conventional flowmetering techniques have utilized the measurement of differential pressure (or change in head) across an orifice, Venturi, nozzle, weir, etc., for the determination of fluid flow rate. As is well known, the incompressible flow through these flowmeters is governed by a 'square law' relationship between differential pressure and flow rate. In many instances, especially in control applications, it is highly desirable to have a flowmetering device whose output is directly proportional to the flow rate. Of the many attempts to produce a 'linear' flowmeter, one of the most interesting devices developed recently is the vibrating-wire flowmeter (*3*). This device makes use of a unique characteristic of a vibrating wire; that is, that its vibration frequency depends on the square root of the tension in the wire. The principle of operation of the flowmeter can be best understood by referring to Fig. 3. A pressure-sensitive diaphragm separates the high- and low-pressure chambers. A steel wire is suspended from an adjustable yoke and connected at its lower end to the centre of the slack diaphragm. Adjustment of the yoke provides an initial (zero flow condition) tension in the wire equal to the weight suspended from the underside of the diaphragm. The length of wire that is free to vibrate is adjusted by means of two bridge supports. It can be shown that the natural frequency of the wire is dependent on the length L, diameter D, density per unit length ρ, and applied tension T. Thus

$$f = \frac{K}{DL}\sqrt{\frac{T}{\rho}}, \text{ where } K \text{ is a constant.}$$

An increase in the differential pressure (δp) across the diaphragm (of area A) will increase the tension in the wire, so that

$$T = (\delta p)A + W$$

Assuming that the flow rate Q through the measuring element (orifice, Venturi, etc.) is proportional to the square root of δp, and assuming that the weight W is negligible compared to $(\delta p)A$, it can be shown that $f = nQ$, where n is a constant. An electromagnet, a pick-up coil, and an 'oscillating' amplifier, are used to provide the necessary means of sustaining the wire vibration. Fig. 4 shows the electronic circuit employed. Once the power supply is energized, current from the plate of the output tube V_2 energizes the electromagnet E which causes the wire to deflect. The pick-up coil P senses the wire deflexion and feeds a signal into the grid of the pre-amplifier tube V_1. Self-sustained oscillations in the amplifier, and thus continuous vibrations in the wire, are made possible by proper phasing of the electronic circuit. Consequently, coupling between the amplifier input and output is solely through the vibrations of the wire. The 'clipper' section of the electronic circuit is provided to facilitate the measurement of the frequency of vibration. (The reader is referred to (*3*) for the operation of the clipper section.) A practical flowmeter utilizing the vibrating-wire measuring device has been developed by the Long Beach, California, Water Department for use in the Long Beach water treatment plant. The device is used with a 42-in orifice to indicate the raw-water flow.

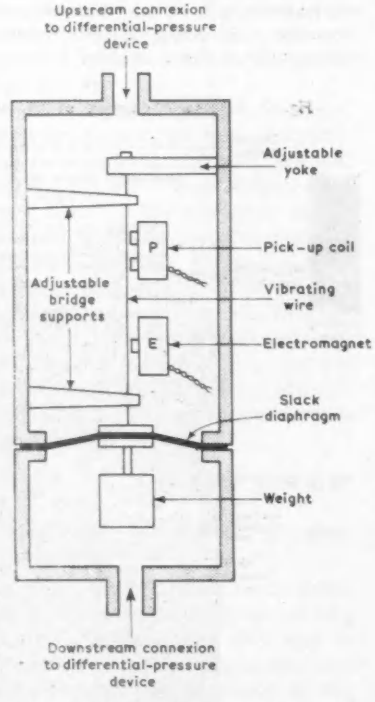


Fig. 3 Vibrating-wire measuring device for differential pressure

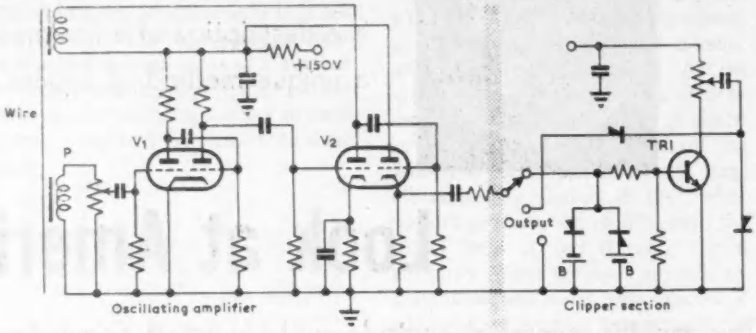


Fig. 4 Circuit for vibrating-wire flowmeter

First electronic telephone central office

The world's first electronic telephone central office was opened recently for customer trial in Morris, Illinois, by Bell Laboratories and Illinois Bell. Originally conceived in the late 1930's at Bell Laboratories, the electronic central office (E.C.O.) represents the results of one of the most massive research and development efforts ever undertaken by a commercial enterprise. This remarkable new system is said to perform electronically all the functions of handling telephone calls.

The E.C.O. brings an unusual range of services to the 300 Morris subscribers who will participate in the first phase of the trial. Subscribers will be permitted to: dial a two-digit code which auto-

matically transfers all subsequent incoming calls to any other local number; have incoming calls transferred to another phone when the original phone is busy; dial two digits instead of seven for frequently-called numbers; and use home extension phones as intercoms simply by dialling a two-digit number. Once the trial is under way, it is expected that other services will be introduced which will allow the subscriber to have an immediate connexion to a busy line as soon as it becomes available, and call a third person into an existing two-party conversation. These new services are made possible through the use of a switching network consisting of 23,000 neon-filled tubes, unique new memory systems, and a control system made up of thousands of transistors and other solid-state devices.

The E.C.O. differs considerably from present telephone switching systems. A few rows of compact cabinets filled with thousands of small plug-in components have replaced the former long, high racks of equipment filled with noisy relays. Most important among the differences is the use of stored-program control, that is, each action to be performed is determined by instructions stored in a memory. The entire program of two and a quarter million bits is stored on four glass photographic plates in what is called the 'flying spot store'. A cathode-ray tube produces a small light which can be positioned to read out 67 different items of information from a photographic plate simultaneously. All the two and a quarter million bits can be read in one-ninth of a second.

Besides the photographic memory, two other principal components make up the central control. These are the barrier-grid store and the central control logic network. The barrier-grid store serves as a temporary or 'scratch-pad' memory for arriving information. The central control logic is made up of nearly 3000 germanium transistors and 20,000 diodes, and has the function of processing and routing control orders. In other words, the logic circuits interpret the incoming information and make the necessary decisions. Once decisions are made, orders are sent from the central control to the switching circuits wherein the physical action of connecting one phone to another is accomplished.

Servo-mechanism computation by root locus methods

An analytical approach to the compensation of servo-systems based on root locus techniques is suggested in a paper by Ross, Warren, and Thaler (*5*). For the case where a lead/lag compensator is used to obtain a specific closed-loop root location and the loop gain is fixed owing to steady-state-error considerations, an expression is developed that explicitly locates the pole and zero of the compensator.

The method is extended to include explicit selection of compensator poles and zeros when cascaded lead/lag networks are used. For the situation in which loop gain restrictions are not present, but the location of the compensator poles and zeros is restricted, it is shown that closed-loop roots are also restricted to certain regions of the s plane. Conversely, if the location of the closed-loop root is specified, the regions in which it lies denote a specific form of compensation (i.e., lead, lag, or cascaded combinations) required to place it there. Rules for the delineation of these 'root relocation zones' are developed, and several design applications are included for illustration. This technique can be a convenient tool when the root locus approach is employed in the analysis of systems of this kind.

Education in control engineering

The sustained growth of industrial and military applications of instrumentation and control in the United States has created a growing need for young engineering graduates having an academic background that includes work with dynamic systems. In many instances, this need is being met with special graduate and undergraduate courses in instrumentation, servo-mechanisms, automatic control, and systems analysis. The number of schools offering this kind of course has been steadily growing, and in most instances, graduate research activity has been developed in accompaniment with the courses. Very important also to control education has been the development of computers and the evolution of computing facilities and centres in the engineering schools.

The Foundation for Instrumentation Education and Research (F.I.E.R.), a non-profit organization dedicated to the promotion of the instrumentation and control field in the United States, has been able to arrange an increasing number of industry-sponsored graduate fellowships for promising young men, with well thought out programs for their own graduate development. Very recently, F.I.E.R. has also provided the impetus for the establishment of a small sponsored research project in one university.

Yet a great majority of the education and research work in this field comes into being in a relatively haphazard way in the United States—typical of our free, unplanned way of doing things. Inspired young men get excited about some new ideas and gravitate to the places which seem to provide the most encouragement and best environment for them and their ideas to develop. The administrators of the large engineering schools carry the very heavy responsibility of providing this encouragement and environment in a wide range of new and, as far as the schools are concerned, competing fields. The amount of top-quality talent is always severely limited. We have no central agency for assignment of priorities to various fields of endeavour. Sponsored research, even by the Government, comes into being as the result of 'free market' negotiations of people with multitudes of unco-ordinated government agencies and industrial firms.

It sometimes seems like a miracle that we have been able to realize the accomplishments that we have in the many specialized fields of endeavour that exist today. There are many of us, especially those who have seen some of the recent developments in Russia, who wonder if some co-ordination might become necessary in order to cope with a very competitive situation that we are already beginning to feel in world markets.

But there is another pressing problem in education, and this exists at the undergraduate level. The evolution of undergraduate engineering curricula, like research and development, has also taken place in a free and easy way. Many educators who are active in the instrumentation and control field are particularly concerned with the fact that the young men who come into control system courses have frequently been poorly prepared to cope with the dynamic nature of the work with physical systems. Thus there are now strong pressures to bring work with dynamic systems of various kinds into the undergraduate curriculum at the earliest possible moment — probably during the second year. Studies are currently under way at the Massachusetts Institute of Technology to work out a sophomore year course in dynamic systems that will be interdisciplinary in nature. It is hoped that this can be developed as part of the program at M.I.T. to revitalize engineering education under a recent grant of $9,275,000 from the Ford Foundation.

Your American Correspondents

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NEWS ROUND-UP

from the world of control

SPACE

Blue Streak resuscitated?

Commonwealth-European space plans

The fear that 'space' will become the prerogative of the U.S.A. and U.S.S.R. in perpetuity—if, in fact, this is not already so for all practical purposes—looks as if it may bring a reprieve for Blue Streak. It will be recalled that this ill-fated British i.r.b.m. was officially abandoned last spring, although whether this meant any great relaxation of activity at Spadeadam, Woomera, etc., is rather questionable. However, the contractors, de Havilland Propellers, were badly hit and have since merged with their associate de Havilland Aircraft—a member of the Hawker Siddeley Group.

The control engineering contribution to ballistic vehicles is the subject of K. C. Garner's article on page 89

The project was said to have cost some £65m, and to have developed a fully operational weapon might well have meant spending at least £35m more, and many consider that this is an underestimate. Yet, after having spent tremendous sums we were left with a nearly complete rocket, plus the technical facilities and trained staff, and little or nothing else to show for our efforts. Meanwhile the Americans and Russians continued to vie with each other in filling space with satellites. Both nations will surely put a man into space soon: as this is written, the Russians have a 6½-ton satellite in orbit, and the Americans have succeeded in firing a chimpanzee-containing vehicle to a height of 155 miles, over a 420-mile range, and recovering the animal safely.

This sad state of affairs seems to have led the Ministry of Aviation—probably well-pushed by the commercial organizations involved—to sound out the French, Germans, Italians and other nations of Europe about the possibility of a joint venture into space. The idea is, of course, most attractive: it is obviously unpalatable to contemplate Europe's being completely cut off from the brave new worlds of the future, and the idea of a 'third force' may not be so unpleasant to European thinking as is often suggested.

Furthermore, Europe has the brains and engineering capability to do the job and, doubtless most Europeans feel, do it rather better, cheaper, etc., than the two upstart nations who are at present hogging all the limelight in space. There is also some hope that satellites can be turned to profit, possibly in the field of communications. However, perhaps the most important argument in favour of the project can be resolved in the question: can Europe afford not to go in for rocket technology if its engineering by-products are as valuable as many think?

Mr Thorneycroft appears to have met with some success in his attempts to get the European powers to join with Britain and the Commonwealth in forming a space 'club'. The French are definitely interested, and it is likely that Blue Streak and their Veronique will form the first and second stages, respectively, of a three-stage vehicle. It has been reported that Britain would not have been unwilling to undertake the project with France alone as partner, but that the French demanded full European co-operation.

The Strasbourg meeting

At the end of January, sixteen nations met in Strasbourg to discuss Anglo-French proposals for the collective development of a satellite-launching vehicle. On the face of it, the proposals were favourably received, although the delegates to the conference did not—could not—bind themselves to any action, before reporting to their respective governments. It is understood that a £70m five-year program is contemplated, with Britain contributing one-third of the cost. The reason for this disproportionate division is that much of the money would be spent in this country, producing Blue Streaks for some ten major launchings.

The official decisions of the various European countries are still awaited, but there is little doubt that Blue Streak's chances of survival are brighter than a year ago.

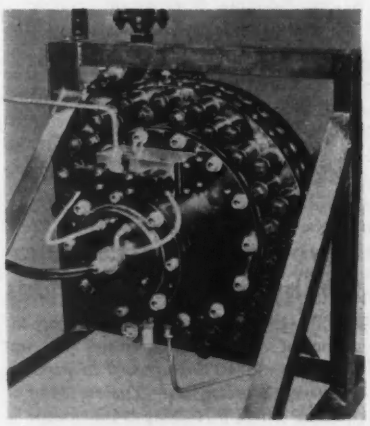
British firms prepare

British industry is obviously preparing for a drive into space, for, as the Strasbourg conference dispersed, a new organization, British Space Development Co, was announced. This has eight members at present (although others are expected to request admission), A.E.I., Associated Television B.I.C.C., Decca Radar, de Havilland (the original contractor for Blue Streak), Pye, Rank, and Rolls-Royce. On behalf of the new company, Sir Robert Renwick remarked: 'We . . . believe the money in space is more than any man ever dreamed of . . . .'

NUCLEAR ENERGY

Plessey's forty-way valve

The burst fuel-element detection system for the C.E.G.B.'s Trawsfynydd nuclear power station, is to incorporate a forty-way selector valve developed by Plessey Nucleonics. *Control* understands that the unusual features of the valve are connected with its reliability, and the intention for it to operate unattended for periods of two



Forty-way selector valve of the burst slug detection system at Trawsfynydd

years. As the valve has a cycling time of 30s it will be expected to cycle more than two million times during the two-year period. The driving mechanism for the valve is grouped in a sub-assembly which incorporates a self-sealing arrangement, so that the mechanism can be speedily replaced while 'on load'. A ratchet indexing mechanism gives accurate location at each index. As 'contained pneumatic operation'—rather than an external driving shaft—is employed, there is no need for rotating shaft seals, and the static seals used are claimed to ensure that there is no leakage.

VACTRIC'S DUST-FREE ASSEMBLY One of an export batch of a.c. motor tacho-generators being assembled in a Plannair dust-free cabinet at the new assembly factory of Vactric (Control Equipment) Ltd. Working in a current of filtered air, the operator is mounting a rotor assembly into a stator

— DATA PROCESSING —

The Hirst Research Centre

The Wembley Research Laboratories of G.E.C. have been renamed The Hirst Research Centre, and reorganized with the aim of securing a closer integration of applied research and development. Under the Director, O. W. Humphreys, the Centre will consist of two main research units, the Central Research Laboratories under V. J. Francis, and the Telecommunications and Engineering Research Laboratories under R. J. Clayton.

During a recent visit to the Centre, *Control* was greatly impressed by the very wide range of work undertaken there, although finding it extremely difficult to decide where control engineering finished and research on lamps, communications equipment and thermo-electric cooling — to mention but a few subjects — began. In the event, most of the visit was taken up by semiconductors (see 'Components' below) and computers.

Computing computer design

Much of the original work on the I.C.T. 1301 data-processing system was done at G.E.C., Wembley, in collaboration with the jointly-owned G.E.C.-I.C.T. company, Computer Developments Ltd. In order to prove the design, a computer consisting of the 1301's electronic circuits, in conjunction with simplified input and output devices, was constructed, and became known as the 1301 Test Bed. Now that this prototype 1301 has served its original purpose, it is being used to study the possibility of designing computers with the aid of a digital computer. The idea is not to play with the existing circuits of the 1301 Test Bed in an attempt to re-design that machine, but to actually use the machine as a tool with which to compute from a given specification, and so obtain as output, basic circuitry, printed board layouts, wiring instructions and overall cost.

Control gathered that, at the moment, the problem is to prepare a machine language capable of defining a specification in terms of the functions a particular machine is required to perform. The design team appear

The Hirst Research Centre's 1301 Test Bed computer, a prototype of the I.C.T. 1301 machine, is now being used to study the possibility of computer design with a computer

to be confident that once this has been done, their aim will be in sight. It was even suggested that a computer-controlled machine could be used to build a computer.

Recording radar data

Equipment for recording the output of precision tracking radars has been ordered from I.C.T. by the Ministry of Aviation. The intention is to record a radar target's azimuth and elevation in digital form on punched cards, but as the radar data must be examined at high rates, it is first recorded on magnetic tape and then replayed into punched-card equipment.

The radar's output consists of digital measurements of the azimuth, elevation and range of the radar beam, together with voltage signals representing the angular distance of the target from the centre of the beam. The readings of the position of the beam itself, will be recorded in digital form directly on the magnetic tape, while the voltage error-signals will first be converted to digital form by high-speed digital-to-analogue converters before being recorded simultaneously on the same tape. A separate equipment will convert the tape to punched cards by replaying it at a slower speed and, via conversion equipment, into a card-punch. The equipment will use solid-state techniques and a measure of self-checking will be incorporated.

Other equipment will take the primary magnetic tape and replay it into an existing real-time computer, so that by examining the computer's output an operator will be able, not only to get a quick appreciation of the target's course, but will also be able to eliminate those parts of the record that are not of immediate interest.

— COMPONENTS —

Controlled semiconductors

During *Control's* recent visit to the G.E.C.'s Hirst Research Centre at Wembley (see above), the increasing impact of semiconductor devices as components for control systems was most evident. Possibly the device of most immediate control engineering interest is the silicon controlled rectifier, or s.c.r., and currents of 50 A and p.d.s of several hundred volts are no longer unusual. The s.c.r. may be thought of as a solid-state version of the thyratron if it is to be used for controlling the speed of an electric motor, for example, or may be regarded as an alternative to the power transistor for use in inverter circuits.

The device was discussed in the August and September 1960 issues of *Control* in *The silicon controlled rectifier* by A. J. Sadler and P. A. Turner.

A disadvantage of the s.c.r., which it has in common with the thyratron, is that it can only be switched from the low-resistance state to a high resistance, by interrupting the anode voltage, or by making it negative. A device which could be switched both

into, and out of, the low resistance ('on') condition by applying signals to control electrodes would appear to have many applications. Work at the Hirst Research Centre has now led to the development of such a four-layer tetrode switch.

The device is a fast, *p-n-p-n* layer structure with leads connected to all the layers. The particular element demonstrated is said to be able to handle currents of some 50 mA in its 'on' state, with a volt-drop of about 1·5 V, and the currents required to turn it 'on' and 'off' are about 2 mA. Switching times of the order of 0·2 μs are claimed. The device is understood to withstand voltages of about 45 V and is therefore attractive for control circuits in low-voltage industrial applications. Its high operating speed, coupled with the fact that the associated circuit is relatively simple, may also make it attractive for data handling and computing machines.

RUGBY'S LONGEST FOR RUSSIA This 61-ft long control board, which the Motor and Control Gear Division of A.E.I. recently shipped to Simon Handling Engineers (a member of the Rustyfa consortium for a Russian tyre factory), is the longest ever built at Rugby Works. One of fifteen for Russia, the board incorporates a 13-ft mimic diagram and will control motors driving plant for the manufacture of rubber pellets from rubber slabs, and their transfer to main storage bins. It will also control the equipment which transfers these pellets from the main bins to process bins at each mixing station. This board, together with others, will be located in a central control room

DEVELOPMENT

N.R.D.C.'s year

The National Research Development Corporation's report and statement of accounts for the year ending June 30, 1960, published recently, impresses upon one that the Corporation continues to be concerned with '(a) the commercial exploitation, mainly by licensing, of patent rights for inventions derived from publicly supported research, and (b) the development of inventions in the public interest, whatever their source, and their subsequent exploitation'.

Arch

The N.R.D.C. has several development projects of interest to the control engineer. 'Automatic process plant control' concerns the development of electronic automatic control equipment suitable for plant automation and process control. A range of standard machines for analogue, and mixed analogue-digital, computing controls is being developed with the idea of assembling these devices into particular systems to suit different applications. Elliott Brothers (London) Ltd, who are sharing the costs with the N.R.D.C., are responsible for this project which has been given the code name Arch—Automatic Register Controlled Hierarchy.

Atlas and Emidec 2400

The Ferranti Atlas high-speed digital computer for scientific or commercial work, is progressing satisfactorily. *Control* understands that the pilot model Atlas, which has been working on test programs at Manchester University, is being dismantled and will be replaced by a production prototype during June this year. The prototype should be in operation by the end of the year. Meanwhile, the pilot model will be re-assembled at Ferranti's Manchester works and used for training purposes and preparing programs for the production Atlas.

The first models of E.M.I.'s Emidec 2400 commercial data-processing system should be delivered this year. The program for further development of this machine has been modified to allow for work on a new fast store and research on magnetic tape equipment. N.R.D.C., having supported research on thin magnetic films, is hopeful that the new store will employ this technique.

Among other work of interest is that on automatic paper chromatography, automatic cotton-spinning, and the ultrasonic flowmeter of the British Scientific Instrument Research Association.

STANDARDS

Process control terms

The British Standard concerned with process control terminology has been revised and a new standard, *B.S. 1523 : Glossary of terms used in automatic control and regulating systems, Section 2 : Process control, 1960*, published. Though similar in scope and arrangement to the now obsolete 1949 version, many of the terms have been re-defined, and the system of subsections has been altered. In most cases the 'preferred' terms only are given, as the B.S.I. considers that the 'non-standard' terms are rapidly falling into disuse. The diagrammatic section has been expanded to include, *inter alia*, figures illustrating normalized attentuation and subsidence ratio.

WATER

Monitoring turbidity

The trend towards the use of laboratory instruments under industrial conditions is increasing, and a particular example where such 'delicate' equipment is being used successfully for continuous measurement in the field, is at the Mythe Waterworks, Tewkes-

NEWSBRIEFS

Graduate courses on *Information engineering* and *Electrical machines: electromechanical energy conversion and automatic control* will run from 1 October, 1961 to 30 September, 1962 in The Electrical Engineering Department, The University of Birmingham, Edgbaston, Birmingham, 15. Details: D. A. Bell, Supervisor of Graduate Courses. (See also 'Courses in control' page 133).

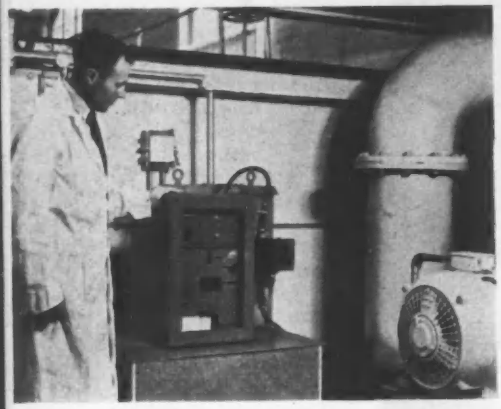
Plastics for electronics industry: Microcell Electronics Division now distribute the plastics materials developed by Emerson & Cuming, Inc., U.S.A.

Three I.C.T. computers to a total value of £200,000 have been ordered by South African Railways, in addition to the I.C.T. 1202 already doing payroll work in Johannesburg. Two 1202's are to do similar work in Port Elizabeth and East London, and a 1201 is to perform various tasks including an analysis of goods carried, a ticket audit and pensions work.

Symposium on the applications of analogue computers will be held on 10 and 11 April, 1961 in the Department of Electrical Engineering, College of Technology, Loughborough, Leicestershire. Details: D. Longley.

Automated rolling mill now in operation at the Ilyich Iron and Steel Plant, Zhdanov, Ukraine, U.S.S.R., said to be the biggest of its type in Europe, is controlled by 'a self-adjusting system controlled by electronic computers'.

The AMPEX CP-100 is a compact, extended-frequency instrumentation tape recorder/reproducer. Tape transport, motor drive amplifier, heads, power converter, controls and all-transistorized plug-in record/reproduce electronics are contained in a single 13¼" x 19" x 33¼" mobile case. The CP-100 operates on 28-volt DC, with 48 to 400 cycle converters available for other power sources. Data is recorded by direct or FM carrier techniques on up to 14 analogue tracks. The CP-100 offers frequency response to 200 Kc at 60 ips or expanded recording time of 24 minutes for 100 Kc data at 30 ips on a standard 10½" reel. Transport tape speeds – 1⅞, 3¾, 7½, 15, 30 and 60 ips – and plug in frequency determining units and equalizers associated with tape speeds, may be quickly changed. The versatile and mobile CP-100 performs reliably over a temperature range of from −50° F to +160° F, up to an altitude of 10,000 feet, in relative humidities to 95%... and is designed to withstand shocks and vibrations encountered in rugged mobile testing applications. This recorder may also be rack mounted if desired. For complete details write Ampex Great Britain Limited, Arkwright Road, Reading, Berkshire, England. AMPEX



Southern Analytical's Sigrist photometer in use at Mythe Waterworks

bury. There a Sigrist photometer of Southern Analytical, has been used for some time to measure water turbidity continuously in order that the process may be controlled, and the performance of the treatment plant studied. Difficulties connected with the instability of the light source and photocell, the effects of colour, and window-fouling and misting, have precluded the general use of photometers in the past. In the Sigrist instrument, however, it is claimed that these difficulties have been overcome.

The photometer compares the flowing water sample with an optical standard of turbidity, continuously, and does this in such a way that any variation within the instrument itself is compensated for.

SYSTEMS

Control system analysis

The Wayne-Kerr organization, known principally as makers of portable electronic measuring equipment, are now extending their field to include the analysis of control systems. Their transfer function computer, originally announced some time ago, is claimed to represent a new and economical approach to the problems of transfer function work. The computer offers an alternative to conventional frequency-response analysis, giving the coefficients of the transfer function directly. More recent work in the Wayne-Kerr Laboratories is concerned with other unconventional equipment. Of particular interest is the 'predictor', which is claimed to predict accurately a future value of a random input. The time for which prediction can be made is limited to approximately one-third of the period of the maximum response frequency of the equipment under test. The predictor was demonstrated at the 'Phys. Soc.' exhibition, and a fuller account of it will be found in our review of the exhibition on page 85 of this issue. It is thought that equipment working on the principles of this device may have process control applications.

EDUCATION

Farewell to night school?

'At whatever age a student who is going on to a technical college finishes his secondary education he should go direct into a technical college course. The needs of such students cannot be adequately met by the evening institute. This is no criticism of the evening institutes themselves . . . .' So we read on opening the White Paper on technical education (*Better opportunities in technical education*, H.M.S.O.) at random. There is no doubt that working in a dull green-and-cream-coloured classroom (when one's contemporaries are studying the humanities in the local Palais de Danse) is good for the budding engineer's spirit, but it is damnably hard work and can be soul-destroying, and the suggestion that night schooling should be discarded is therefore welcome.

The White Paper does, however, make a number of other proposals. It suggests that more care should be taken in the selection of students for courses, and that there should be experiment with full-time induction courses and tutorial methods. National Certificate and Diploma courses for students aiming to become at least high-grade 'technicians' are called for, as are technician courses devised for particular industries, 'craft' courses and courses for 'operatives'; O.N.C. courses should last two instead of three years, and the standards of entry raised; new general courses, leading to either technician courses or O.N.C. and Diploma courses, are proposed; craft courses should be modified and courses for operatives vigorously developed; more time should be provided under day-release schemes—'No student should have to rely wholly on evening study', and sandwich courses and block release courses should be increasingly developed.

TRANSPORT

Counting bus passengers

The efficient operation of modern passenger transport systems relies to a large extent on the proper planning of running schedules, and this is dependent upon accurate information of passenger traffic conditions.

In 1957 Mr N. Tuft, General Manager of the West Yorkshire Road Car Co., in collaboration with the Electrical Measurement Division of Elliott Brothers (London) Ltd, developed an electrical method of analysing and correlating the actual operational data. In this 'loadmeter' system a microswitch is located under each seat. When a seat is occupied by a weight of twenty-eight pounds or more, the switch closes, causing one milliamp to flow in a circuit of a chart recording instrument. The latter is calibrated to indicate full-load condition for full scale deflexion, i.e. one milliamp per seat in a 75-seater vehicle gives 75 mA full scale deflexion of the instrument, and increments of one passenger can be readily detected. The loadmeter thus provides a continuous written record of the number of seats occupied, and also running times of the

NEWSBRIEFS

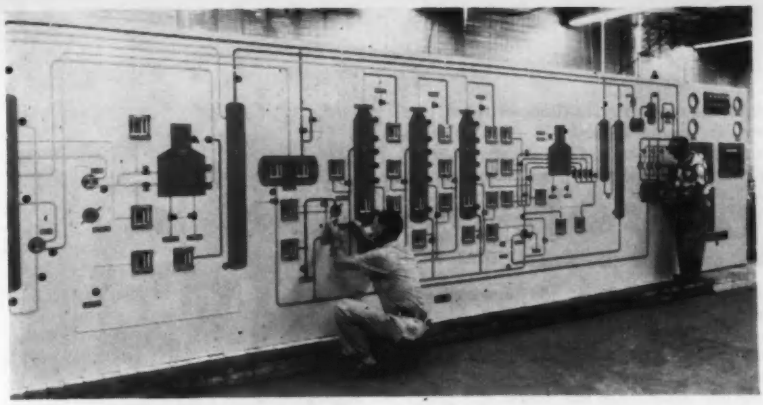
Beama—The British Electrical & Allied Manufacturers' Association—is to put member-firms in touch with makers of complementary equipment with a view to a joint sales effort, joint market research, and collective exhibitions overseas.

Expert Industrial Controls Ltd, Lount Works, Ashby-de-la-Zouch, Leicestershire has been formed by amalgamating Sharp Control Gear Ltd and Electran Coil Co. Ltd.

Process optimization will be the subject of a one-day symposium to be held as part of the Third Congress of the European Federation of Chemical Engineering, 20-26 June, 1962. Papers on such subjects as *The significance of control in process optimization*, *Progress in the control of heat transfer equipment and distillation columns*, and *The computer-controlled plant* are invited. Details to The General Secretary, The Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1, before 30 April, 1961.

Texas-I.T.&T. agreement: Texas Instruments Inc. and International Telephone & Telegraph Corp. are to 'exchange non-exclusive patent licences and technical information concerning semiconductor components. Texas Instruments will also supply a portion of I.T.&T.'s needs for semiconductor devices and components.'

Infra-red analyser by Mine Safety Appliances, Glasgow, detects any carbon monoxide leakage within a cold room where engines are tested at temperatures down to −100°F, at the Ford Motor Co. Dagenham. A second instrument has been ordered for Ford, Birmingham.



PANEL FOR PETROBRAS One of 39 sections of five instrumented graphic panels—225·5 ft in total length—which Minneapolis-Honeywell Regulator are assembling for the eight-unit Duque de Caxias refinery of Petroleo Brasileiro. The main contractors are Foster-Wheeler. The Honeywell instrumentation includes miniature pneumatic indicating, recording and controlling devices, and electronic potentiometers and pressure gauges, as well as thermometers, flowmeters, differential converters, transmitters and so forth, external to the control centres. The panel for the catalytic cracker alone contains 92 instruments

engine of the bus and peak load conditions against a time scale.

Control understands that in recent months the system has been successfully used by the Maidstone & District Motor Services, in an investigation of a complex traffic reorganization program. Furthermore, the London Transport Executive (Country) and the East Kent Road Car Co. are also investigating the possibility of adopting the loadmeter system.

PETROLEUM

Automated oil field

The 'world's first fully mechanized and automated oil field' is being constructed in the Tatar Republic, U.S.S.R., according to *Soviet News*. The field is near Leninogorsk in the Volga valley, and water will be injected into the seams, so keeping 'hundreds of oil wells gushing for many years'. Automatic control devices will be installed at group collecting centres to which oil and gas will be delivered through a single pipe. It is suggested that the field will have a staff of about 100 persons only.

720-mile Indian pipeline

A £33 m crude-oil pipeline is being laid 720 miles across north-east India by Mannesmann of Düsseldorf and Saipem of the Italian E.N.I. group, under the supervision of The Burmah Oil Co. (Pipe Lines) Ltd. Said to form one of the most technically advanced crude-oil transportation systems of its size in the world, the line will be equipped with an extensive radio communications network and push-button controls for the remote operation of pumping stations and telemetering services.

NEWSBRIEFS

Dip. Tech. (Henlow): technical cadets taking the course of the R.A.F. Technical College, Henlow, are now eligible for the Diploma in Technology.

Ampex Videotape recorders are now handled by Ampex Great Britain Ltd, and no longer by Rank-Cintel. This follows from the establishment of an Ampex subsidiary in England.

Reactor simulator: the U.K.A.E.A. have ordered a 200-amplifier analogue computer from Short's Precision Engineering Division. Intended to simulate the behaviour of a complete nuclear power station, it will be installed at the Calder Operations School.

Space electronics group being formed by Decca Radar, will be situated in new laboratories at Somerton Airport, Cowes, Isle of Wight.

Engine condition analysers by Ultra Electronics have been ordered by B.O.A.C. for use on their Comet IV aircraft.

High-pressure hydraulic equipment (up to 7100 lbf/in² maximum pressure) comprising fixed-capacity piston pumps, directional valves and control valves, is now available in the Keelavite/Gury range from Keelavite Hydraulics. Marketing rights in the U.K. and Commonwealth for Hydro-Titan hydraulic axial piston units have also been obtained by Keelavite.

Univac for Japan: a $2m Univac II computer is being shipped from New York to the Tokyo Electric Power Co. Data will be fed from some thirty substations in the Tokyo area to the computer in order to determine power requirements and peak loads.

National-Elliott 803 computer installed in the Central Research Institute of Complex Automation, Moscow, has been operating on a two-shift basis since it was handed over on August 22, 1960.

Postal mechanization: 'automatic mail, segregating, grading and facing equipment', similar to that ordered by the British P.O., has been ordered by the Canadian Post Office from Elliott Brothers (London) Ltd.

Stroboscopes in the 'Strobolyser' range of Watford Instruments are now produced, sold and serviced by Furzehill Laboratories.

QUALITY

Danish society formed

Dansk Forening for Industriel Kvalitetskontrol—Danish Society for Quality Control — has been set up, the Society's Secretary, K. Haltou-Nielsen, informs *Control*. The object of the Society is to increase the competitiveness of Danish industry by disseminating information on quality control, exchanging information between members and informing them of developments outside Denmark. The Society has joined the European Organization for Quality Control (E.O.Q.C.), whose British correspondent is, of course, the British Productivity Council.

EDUCATION

Courses in control

Various technical courses on control engineering start in the near future. These include: *Simple code for the Stantec-Zebra computer*, at Woolwich Polytechnic, six weekly lectures from 22 or 23 February, to 12 or 13 April; *Automatic control and servo-mechanisms*, Constantine Technical College, Middlesbrough, ten weekly lectures from 2 March; *Control engineering*, Nottingham and District Technical College, one week during April and May; *Electrical control systems*, Kingston-upon-Hull College of Technology, six weekly meetings from 17 May; *Servo-mechanisms and automatic controls*, Sheffield University, 18 April to 19 May; *Analogue computing methods for engineers*, Sheffield University, 13–16 June; *Numerical analysis and computer programming*, Liverpool University, 5–15 April; *The electronic digital computer: its application to control problems in industry and commerce*, Norwood Technical College, six weekly lectures from 14 February.

New for Control

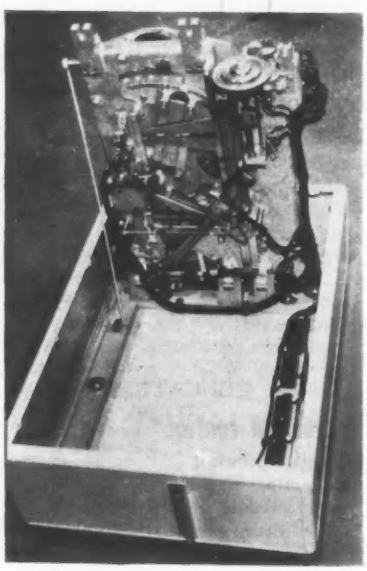
A monthly review of system components and instruments

For further information, circle the appropriate number on the reply card facing page 163

ANALOGUE COMPUTER

mechanical operation

A computer by Elliott receives two direct-voltage inputs, and uses a feedback servo-system to operate potentiometers and so provide an output of two direct-voltages after the required calculation has been done mechanically. Overall accuracy is in the order of 1%. Although



High overall accuracy

this computer uses electrical inputs, the system is readily adaptable to accept direct mechanical (rotational) inputs from servo-systems.

Circle **No 485** on reply card

MEASURING UNIT

time and frequency

A digital time- and frequency-measuring unit by Venner Electronics will measure frequency up to 1·1 Mc/s and period; it will also measure simple counting and time intervals in 1-μs or larger units. The crystal oscillator is oven-controlled, and its output and the outputs of the decade divider-chain are available externally for use as clock pulses.

The T.S.A. 3336 uses transistor plug-in circuit modules, and can be supplied with outputs suitable for operating a printer or perforator. It may be operated from 100- to 125-V 50-c/s supplies, or from 12 V d.c.

Circle **No 486** on reply card

D.C. TACHOGENERATOR

low inertia

A size-11 tachogenerator is intended for use where high linearity of output voltage with respect to speed is required. The output is 3 V/(1000 rev/min), with a maximum speed of 4000 rev/min, and linearity is given as 0·25%. Minimum load resistance is 5000 Ω, and maximum ripple is 10%.

Running torque is kept low by the use of wire brushes, and the inertia is 2 g cm^2. Made by Vactric (Control Equipment) Ltd, this unit conforms to International Frame-size standards, and its overall length is just under 2$\frac{1}{8}$ in.

Circle **No 487** on reply card

D.C. MOTORS

chronometrically governed

A series of constant-speed motors are available from A. W. Haydon (U.S.A.). The 1·5-V model is claimed to work for more than two years from a standard flashlight-battery, the constant speed of 150 rev/min being maintained by a governor with a patented balance-wheel-hairspring mechanism. The accuracy is given as $\pm$ 10 s in 24 h, with an input voltage varying from 0·9 to 1·8 V. The motor weighs 3 ozf, and measures 1$\frac{1}{4}$ × 2$\frac{1}{2}$ × $\frac{1}{2}$ in; windings can be supplied for operation from 0·5 to 12 V d.c.

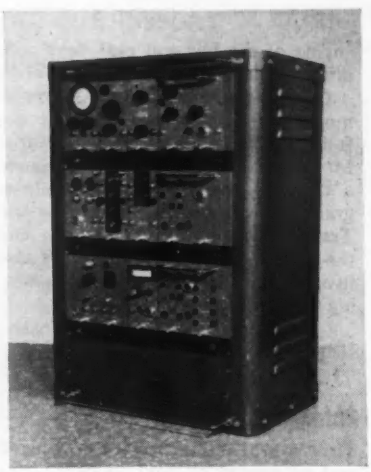
Circle **No 488** on reply card

COUNTING EQUIPMENT

complete modular range

An equipment by Ericsson, based on the A.E.R.E. 2000, comprises a comprehensive range of standard-size units for nucleonic counting applications. These plug into shelf units each of which will accommodate five single-width modules.

The range includes a fast pre-scaling unit, a slow scaling unit, a discriminator, a 3-Mc/s amplifier, a quench unit giving 6 switch-selected paralysis times (100–600 μs), a timing unit, an e.h.t. unit, a scintillation head, coincidence and anti-coincidence units, linear and logarithmic ratemeters, a potentiometer unit, a single-channel pulse-analyser, a read-out unit, a G.-M. probe, and power supply



Self-contained

units. Thermal delays fitted in the shelf units allow the thermionic tubes to reach operating temperature before the e.h.t. is applied.

Circle **No 489** on reply card

SPECTRO-PHOTOMETER

u.-v. and visible spectra

Now being produced by Perkin-Elmer is the 137UV spectro-photometer. Typical resolution is 0·2 mμm at 250 mμm, with a noise level of less than $\frac{1}{2}$%. Scanning time is normally 2 min in each region, but a slower time of 8 min is provided for scanning very sharp absorption bands. The record is linear with respect to both frequency and wave-length, and an automatic gain-control holds the pen-response steady despite large energy fluctuations.

Circle **No 490** on reply card

HARMONIC ANALYSER

portable unit

A harmonic analyser by the Telephone Manufacturing Company is designed to measure the magnitude and frequency of harmonic interference from electric traction and power distribution systems into nearby telecommunication systems.

The instrument comprises an input attenuator-panel, an oscillator and calibrator panel, and 12 plug-in selective measuring-units each accepting one odd

Harmonic interference detector

harmonic between 50 and 1500 c/s. Direct filtering removes all but the relevant frequency. The output from each of the 12 measuring units is displayed on a meter covering 0–100 mV, the meters providing a simultaneous display of the fundamental and each of the odd-harmonic voltages. Indication accuracy is about ± 1%.

Circle **No 491** on reply card

FUNCTION GENERATOR

very low frequency

Now commercially available, Advance Components' S.G.88 function-generator uses a mechano-optical system to generate waves of any form provided that they are derived from single-valued, repetitive functions. The conventional oscillator is replaced by disks, printed with an opaque pattern representing the polar co-ordinates of the desired wave-shape, which are scanned by a narrow light beam. (A note on this may be found in *Ideas Applied*, page 103, *Control*, January 1960.)

The output frequency is steplessly variable from 0·005 to 50 c/s, calibration accuracy being ± 1%. Output voltage is from 200 μV to 22 V peak-to-peak, high impedance; amplitude varies by not more than 1 dB over the entire range. The unit will operate from any normal 50- to 60-c/s mains supply.

Circle **No 492** on reply card

QUICK LOOKS

Trace interrupter. This unit is available from Bryans Aeroquipment for use in conjunction with their X-Y co-ordinate plotting table. It produces three trace patterns: a series of short dashes with a low mark/space ratio; a series of long dashes with a high mark/space ratio; a series of alternating long and short dashes. A frequency control permits the marking rate to be adjusted to suit any given pen speed.

Circle **No 493** on reply card

Automatic lighting-control. A unit (D.S.20B) available from Britec will control the switching of up to 6 A at 200 V a.c. (resistive load) according to ambient illumination. A delayed-action device prevents switch-on by brief fluctuations of ambient illumination caused by such events as lightning. The control level is simply adjusted by an internal potentiometer.

Circle **No 494** on reply card

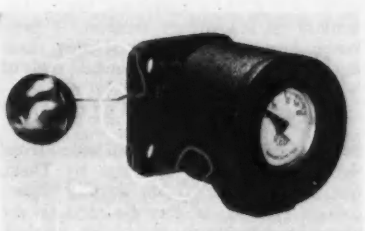
Oscilloscope. The calibrated sweep-range of a dual-beam oscilliscope by Dumont (U.S.A.) extends from 1 s/cm to 1 μs/cm in nineteen steps. Sweep may be expanded without distortion up to five times full scale, and any 10-cm portion of the sweep can be positioned on the screen. Available in the U.K. from Aveley Electric.

Circle **No 495** on reply card

Magnetic susceptibility meter. A unit by Electronic Instruments Ltd measures the magnetic susceptibility of para- and diamagnetic materials, and also may be used for testing samples for ferro-magnetic impurities. It is based on a magnetic bridge-circuit which is unbalanced by the insertion of the sample; the unbalance is detected by a Hall-effect detector in the central limb.

Circle **No 496** on reply card

Level indicator. Intended primarily for use in cooling-water header-tanks on Diesel locomotives, the R. & G. 1810 switch gives continuous indication of



water-level and closes an alarm contact at low level. The mercury switch has a rating of 6 A at 110 V d.c., and the tube snaps through 90° at operating level thus obviating intermittent contact. Manufactured by Bayham.

Circle **No 497** on reply card

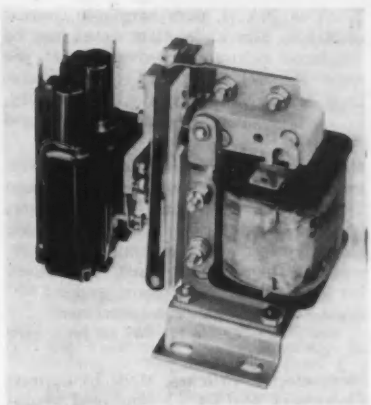
Stepper motors. A thin, ultra-quiet stepper-motor by Haydon (U.S.A.) may be operated at up to 2400 steps/min. Rated at 27 V d.c., this unit has a rotor step-angle of 30°/cycle, and positive magnetic detenting occurs at each of the 12 angular positions whether or not the coils are energized.

Circle **No 498** on reply card

Precision potentiometers. A series of low-torque potentiometers intended for servo applications is available from Ancillary Developments. Graded ball-races and precious-metal contacts are used to give a low inertia, and a starting-torque of 0·5 gf cm. Linearity is given as 0·1%.

Circle **No 499** on reply card

Vacuum switch. B. and R. Relays' switch type 183 is capable of switching loads up to 2 kW at voltages ranging up to 3 kV. It is operable by their relays C.12



(d.c.) and C.62 (a.c.). In the above illustration it is mounted on a relay and housed in a plastics cover; as such it is designated type 85.

Circle **No 500** on reply card

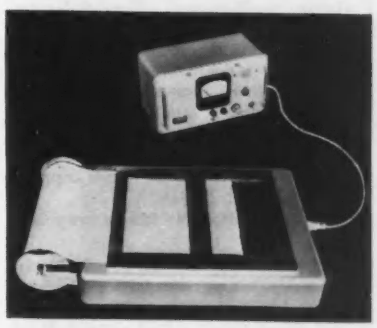
Silicon rectifiers. Rated at a peak-inverse voltage of 1500 V, International Rectifiers' 1N1130 and 1N1131 operate at 300 mA. Reverse leakage is as low as 100 μA at 75°C, and these stud-mounted units will operate at temperatures up to 150°C.

Circle **No 501** on reply card

Sound spectrometer. A portable instrument by Advance Components will measure sound in the frequency range 20–12,000 c/s, and analyse it in octave bands with built-in filters. A crystal microphone is provided, but the amplifier will accept inputs from vibration pick-ups and similar devices in the range 3 μV to 8 V; input impedance is 10 MΩ.

Circle **No 502** on reply card

Radio-activity monitor. A unit by Stonebridge Electrical measures the radio-active contamination present on the hands. The hands are placed on two windows in the cover, which are protected by a sheet of paper. Each of the



two windows has 3 counter-tubes, making a total of 6 which are normally connected in parallel, but which may be switched for individual background-testing.

Circle **No 503** on reply card

R.M.S. voltmeter. Ballantine Laboratories' (U.S.A.) model-350 meter measures voltages of 0·1 to 1199·9 V, which are displayed on a 5-digit indicator. The frequency of the input may be from

50 c/s to 20 kc/s, with harmonic content to 50 kc/s. Sine and square waves may be measured accurately provided that the ratio of peak to r.m.s. is not greater than 2 : 1. Available via Sylvan Ginsbury.

Circle **No 504** on reply card

Inductance and capacitance meter. With minimum full-scale range of 0–3 μH and 0–3 pF, the Solartron MM906 covers 0–300 μH and 0–300 pF in five ranges. Accuracy is ± 3%, maintained with resistive loads of 20 kΩ shunt, 10 Ω series, for inductance measurement, and 0·1 MΩ shunt for capacitance measurement.

Circle **No 505** on reply card

Photo-electric switches. Made by Cannon Electronics, the T.U.13 combined photo-head and light-source uses a photo-transistor, and is constructed to withstand rough treatment and vibration. It senses light/dark variations, and may be used in conjunction with batch or decade counters.

Circle **No 506** on reply card

Sealed switch. Dowty's Microseal switch will operate at altitudes up to 60,000 ft

in ambient temperatures between − 75 and + 75°C. The action is double-pole, double-throw, and the switch is water-proof. Weight is seven ounces.

Circle **No 507** on reply card

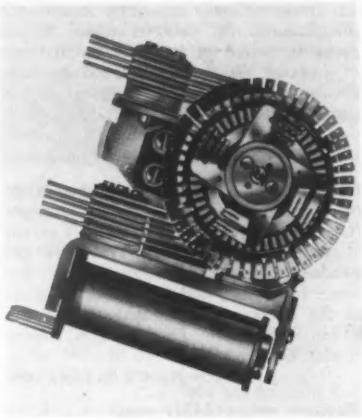
Portable oscilloscope. The Solartron CD1014.2 has two identical Y-axis amplifiers operable at d.c. to 5 Mc/s, and with a sensitivity range from 100 mV/cm to 50 V/cm with measuring accuracy of ± 5%. Time-base range is 1 cm/μs to 1 cm/s with ± 5% measuring accuracy. The instrument weighs 22 lbf, and will operate from 45- to 66-c/s mains supplies at 90–130 V and 200–240 V.

Circle **No 508** on reply card

Gearhead. A size-10 ball-bearing gearhead by Vactric has standard ratios from 10 : 1 to 1000 : 1, and a maximum static torque of 2½ lbf in. It is intended for light-duty servo work.

Circle **No 509** on reply card

Stepping relay. Thorn Electrical Industries are producing a 3-in-1 rotary stepping-relay which consists of a standard relay, a ratchet-driven rotary switch, and a ratchet-driven stepping-relay with two cams which open or close double-contact springs in accordance with the cam pattern. Contacts of the rotary switch-bank



will carry 0·5 A, steady state, or will interrupt 0·1 A at 50 V d.c. with a resistive load.

Circle **No 510** on reply card

Rechargeable battery. A unit 4¼ in long by 1¼ in diameter may be recharged simply by plugging it into an a.c.-mains supply of 110–240 V. Voltages available are 2·5, 3·5, 5·0, and 6·0 V. Made by Chilton Electronic Products.

Circle **No 511** on reply card

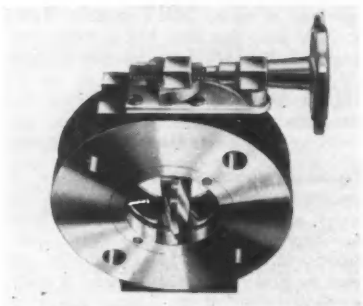
Low-activity sample monitor. The SM1, made by E.M.I., measures the radio-activity of low-energy samples. A two-range linear ratemeter facilitates reading, and an electromechanical register is also provided.

Circle **No 512** on reply card

System error bridge. Available from Sylvan Ginsbury is a bridge by Theta Instruments (U.S.A.) for testing flight-control systems; it may be used to replace transducers such as the vertical gyro and magnetic compass. Angular inputs accurate to 20′ may be dialled into the auto-pilot; the resolution is 4′.

Circle **No 513** on reply card

Pivoted disk valve. The Winn Flexiseat valve is claimed to give 'spot-tight' closure by the use of a ring of flexible material (moulded round a metallic core)



which is located in an annular groove in the valve body. Shortly to be available, the initial range will be in sizes from 3 to 6 in, for water, gas, air or oil at pressures up to 150 lbf/in².

Circle **No 514** on reply card

INDUSTRIAL PUBLICATIONS

X-ray analyser. Cambridge Instrument's Microscan is described in an illustrated publication, list 177/2.

Circle **No 515** on reply card

Platinum metals: a booklet from Engelhard Industries lists some of the industrial uses of platinum metals.

Circle **No 516** on reply card

Tape reader. Creed's model-92 tape-reader is described in their publication 135-001-1E.

Circle **No 517** on reply card

'A complete service in industrial heat engineering' is the title of an illustrated booklet from The Incandescent Heat Co.

Circle **No 518** on reply card

Fixed-capacity piston pumps are the subject of a leaflet from Keelavite Hydraulics.

Circle **No 519** on reply card

Split-field d.c. motors, sizes 11 and 15, are described in data sheets V.P. 4442 and V.P. 4443 respectively from Vactric (Control Equipment) Ltd.

Circle **No 520** on reply card

Semiconductors. Abridged technical data on Ediswan Mazda semiconductors is given in a recent A.E.I. catalogue.

Circle **No 521** on reply card

Valves for nuclear applications by Blakeborough are the subject of their publication No 252.

Circle **No 522** on reply card

Miniature oxide resistors by Welwyn are described in an illustrated brochure.

Circle **No 523** on reply card

Nickel alloys and their uses are featured in a publication from Henry Wiggin.

Circle **No 524** on reply card

Sliding-head automatic lathes for producing long slender workpieces are the subject of a catalogue from Dowding and Doll.

Circle **No 525** on reply card

Mechanical handling equipment by A. and C. Jenner is described in their illustrated brochure.

Circle **No 526** on reply card

Instruments and controls by Servomex are illustrated in their abbreviated catalogue.

Circle **No 527** on reply card

Compagnie générale de télégraphie sans fil. An illustrated book (in French) details the activities of the C.S.F. from 1910 to the present day.

Circle **No 528** on reply card

'Electrical contacts' is the title of a new version of Johnson, Matthey's publication 1302.

Circle **No 529** on reply card

Components, including potentiometers, are shown in a catalogue from Ancillary Developments.

Circle **No 530** on reply card

LOOKING AHEAD

Unless otherwise indicated, all events take place in London. B.C.A.C. British Conference on Automation and Computation. B.C.S. British Computer Society. Brit.I.R.E. British Institution of Radio Engineers. I.C.E. Institution of Civil Engineers. I.Chem.E. Institution of Chemical Engineers. I.E.E. Institution of Electrical Engineers. I.Mech.E. Institution of Mechanical Engineers. I.Prod.E. Institution of Production Engineers. I.S.A. Instrument Society of America. R.Ae.S. Royal Aeronautical Society. S.B.A.C. Society of British Aircraft Constructors. S.I.T. Society of Instrument Technology.

FRIDAY 10 FEBRUARY 1961
The detection of radiation by G. Ballard. 7 p.m. Pepys House, 14 Rochester Row, Westminster, S.W.1. Junior Institution of Engineers.

Process control by R. M. J. Withers. 7 p.m. Gosta Green College of Technology, Birmingham. S.I.T.

MONDAY 13 FEBRUARY 1961
Punched card operation in passenger transport world by D. Eyres. 7.30 p.m. Livesey Clegg House, 44 Union Street, Sheffield, 1. Junior Institution of Engineers.

WEDNESDAY 15 FEBRUARY 1961
High speed digital applications of transistors by M. L. N. Forrest, 7 p.m. at Bristol College of Science and Technology. Brit.I.R.E.

Hinchley Memorial Lecture: *Science and technology and the developing countries*, by P. M. S. Blackett. 5.30 p.m. I.Chem.E.

Inertial navigational systems by E. W. Anderson. 7 p.m. at Adelphi Hotel, Liverpool. Brit.I.R.E.

WEDNESDAY 15—FRIDAY 17 FEBRUARY 1961
1961 International Solid-state Circuits Conference. University of Pennsylvania and the Sheraton Hotel, Philadelphia, Pa., U.S.A.

THURSDAY 16 FEBRUARY 1961
Transistors and all that by L. J. Davies. Central Hall, Westminster. I.E.E.

Instrumentation at the British Sugar Corporation by R. M. J. Withers. 7.15 p.m. The University, Leicester. S.I.T.

FRIDAY 17—TUESDAY 21 FEBRUARY 1961
24th International Components Show, Parc des Expositions, Paris, France.

4th International Exhibition of Electronic Components. Details: F.N.I.E., 25 Rue de Lubeck, Paris 16, France.

MONDAY 20—SATURDAY 25 FEBRUARY 1961
International Convention on Semi-conductor Devices. Details: Société Francaise des Electroniciens et des Radioélectriciens, 10 Avenue Pierre-Larousse, Malakoff (Seine) France.

WEDNESDAY 22 FEBRUARY 1961
New steel-making processes and their control problems by P. A. Young. 7.30 p.m. Cleveland Scientific and Technical Institute, Corporation Rd, Middlesbrough. S.I.T.

FRIDAY 24 FEBRUARY 1961
Computers and structural design—the present position and future trends by R. E. Rowe. 6.30 p.m. College of Advanced Technology, Gosta Green, Birmingham. Institution of Structural Engineers, 11 Upper Belgrave St, London, S.W.1.

MONDAY 27 FEBRUARY 1961
Numerical analogue control of machine tools by O. S. Puckle. St James's Restaurant, Derby. 7 p.m. I.Prod.E.

TUESDAY 28 FEBRUARY 1961
Three terminal bridge measurements and automation by V. S. Griffiths. 7 p.m. S.I.T.

FRIDAY 3 MARCH 1961
Helicopter approach aids by H. W. Mitchell and S. G. Lennox. 7 p.m. R.Ae.S., 4 Hamilton Place, W.1.

TUESDAY 7 MARCH 1961
Guided weapon control equipment by John Dent. 6 p.m. R.Ae.S., 4 Hamilton Place, W.1.

WEDNESDAY 8—FRIDAY 10 MARCH 1961
11th Annual I.S.A. Conference on *Instrumentation for the Iron and Steel Industry*, Roosevelt Hotel, Pittsburgh, Pa., U.S.A. Details: Richard R. Webster, Jones & Laughlin Steel Corp. Res. Lab., 900 Agnew Avenue, Pittsburgh 30, Pa., U.S.A.

THURSDAY 9 MARCH 1961
Design, application and selection of automatic control valves by P. Stone. 7 p.m. M.A.N.W.E.B. Industrial Development Centre, Liverpool. S.I.T.

FRIDAY 10 MARCH 1961
Control problems of nuclear power stations by R. B. Quarmby. 7 p.m. Gosta Green College of Technology, Birmingham. S.I.T.

MONDAY 13 MARCH 1961
A one-day informal discussion on cybernetics. I.Mech.E.

WEDNESDAY 15 MARCH 1961
Burst slug detection data display at Bradwell by J. O. Ross. 7 p.m. S.I.T.

Initial experience on the use of a digital computer for burst slug detection by J. L. W. Churchill. 7 p.m. S.I.T.

THURSDAY 16 MARCH 1961
Recent developments in industrial electronics by E. Metcalf. 7.15 p.m. Derby and District College of Technology, Kedleston Road, Derby. S.I.T.

MONDAY 20—THURSDAY 23 MARCH 1961
I.R.E. National Convention, New York.

MONDAY 20—FRIDAY 24 MARCH 1961
2nd conference on *X-ray analytical methods*. Sponsored by Research and Control Instruments in conjunction with Dept of Geology, Manchester University. Details: Conference Secretary, Research and Control Instruments Ltd, 207 Kings Cross Road, London, W.C.1.

TUESDAY 21—SATURDAY 25 MARCH 1961
10th Electrical Engineers Exhibition, Earls Court. Details: Mr. Joyce, Electrical Engineers Exhibition, 6 Museum House, 25 Museum St., London, W.C.1.

WEDNESDAY 22 MARCH 1961
Some impressions of instrumentation in the U.S.S.R. by E. N. Martin. 7.30 p.m. Cleveland Scientific and Technical Institute, Middlesbrough. S.I.T.

THURSDAY 23 MARCH 1961
Electromagnetic flowmeters by Leo M. Bennett. 7 p.m. Lecture Theatre, Administration Bldg, Associated Ethyl Co Ltd, Oil Sites Rd, Ellesmere Port, Wirral. S.I.T.

MONDAY 27—FRIDAY 31 MARCH 1961
3rd Symposium on *Temperature—Its measurement and control in science and industry*. Veteran's Memorial Hall and Deshler-Hilton Hotel, Columbus, Ohio, U.S.A. Sponsors: I.S.A., American Institute of Physics, National Bureau of Standards. Details: Meetings Manager, I.S.A., 313 Sixth Avenue, Pittsburgh 22, Pa., U.S.A.

TUESDAY 28 MARCH 1961
Automatic optimisation by P. E. W. Grensted. 5 p.m. S.I.T.
The development of an optimising controller by P. F. Sutherby. 7 p.m. S.I.T.

WEDNESDAY 29 MARCH 1961
One-day conference on *Lower costs and higher quality by instruments and control*. College of Technology, Gosta Green, Birmingham. S.I.T. Details: D. Smith, I.C.I. Ltd, Metals Division, Kynoch Wks, Witton, Birmingham, 6.

FRIDAY 7 APRIL 1961
One-day meeting on *Aids to training in automatic control*, at Northampton College, London, E.C.1. Registration: C. D. M. Johnston, 75 Herons Wood, Harlow, Essex.

MONDAY 17—WEDNESDAY 19 APRIL 1961
7th National U.S.A. Symposium on *Instrumental methods of analysis*. Shamrock-Hilton Hotel, Houston, Texas, U.S.A. Details: Meetings Manager, I.S.A., 313 Sixth Avenue, Pittsburgh 22, Pa., U.S.A.

TUESDAY 18—WEDNESDAY 19 APRIL 1961
Science and industry—the problem of communication. Brangwyn Hall, Swansea. Registration: D.S.I.R. Liaison Officer for Wales, Block II, Government Bldgs, Gabalfa, Cardiff.

WEDNESDAY 19 APRIL 1961
The design, application and selection of automatic control valves by P. Stone. 7 p.m. The Conference Room, Roadway House, Oxford St, Newcastle upon Tyne, 1. S.I.T.

Electronic telephone exchanges by T. H. Flowers. 7 p.m. S.I.T.

THURSDAY 20 APRIL 1961
One-day symposium on *Air Traffic Control*. R.Ae.S., 4 Hamilton Place, W.1.

THURSDAY 20 APRIL—THURSDAY 4 MAY 1961
Engineering, Marine, Welding and Nuclear Energy Exhibition, Olympia.

TUESDAY 25 APRIL 1961
Instrumentation in the iron and steel industry by A. H. Pople. 7 p.m. S.I.T.

SUNDAY 30 APRIL—THURSDAY 4 MAY 1961
7th National aero-space instrumentation symposium. Adolphus Hotel, Dallas, Texas. Details: W. J. Gabriel, Convair Division, General Dynamics Corp, Ft. Worth, Texas, U.S.A.

LOOKING FURTHER AHEAD

WEDNESDAY 3—THURSDAY 4 MAY 1961
Railway modernization. A conference organized jointly by I.C.E., I.Mech.E., and I.E.E. Details: I.C.E.

WEDNESDAY 3—SATURDAY 13 MAY 1961
British Columbia International Trade Fair, Exhibition Park, Vancouver, Canada.

MONDAY 8—WEDNESDAY 10 MAY 1961
4th National I.S.A. Power Instrumentation Symposium. La Salle Hotel, Chicago, Ill., U.S.A. Details: Meetings Manager, I.S.A., 313 Sixth Avenue, Pittsburgh 22, Pa., U.S.A.

TUESDAY 9—WEDNESDAY 17 MAY 1961
International Exhibition of Measurement, Control, Regulation and Automation (Mesucora) and 58th Exhibition of French Physical Society, C.N.I.T., Paris. Secrétariat Général, 40, rue de Colisée, Paris, 8, France.

WEDNESDAY 10—FRIDAY 12 MAY 1961
Pulp and Paper Instrumentation Symposium. Northland Hotel, Green Bay, Wisc., U.S.A. Sponsors: I.S.A. and T.A.P.P.I. Details: Meetings Manager, I.S.A., 313 Sixth Avenue, Pittsburgh 22, Pa., U.S.A.

An international conference on *Materia's handling*. Southport. Details: Institute of Materials Handling, 69 Cannon St, London, E.C.4.

MONDAY 26 JUNE—SATURDAY 1 JULY 1961
International Measurements Conference, (Imeko), Budapest. Details: Prof. J. F. Coales, Cambridge University, Trumpington St., Cambridge, or Imeko Secretariat, Budapest 5, P.O.B. 3, Hungary.

TUESDAY 27—FRIDAY 30 JUNE 1961
A conference on the *Social and economic effects of automation*, sponsored by members of the B.C.A.C. Applications for tickets to The British Institute of Management, 80 Fetter Lane, London, E.C.4.

SUNDAY 16—FRIDAY 21 JULY 1961
4th International Conference on *Medical Electronics* at the Waldorf-Astoria, New York. Sponsors: I.R.E., A.I.E.E., I.S.A. Details: Institute of Radio Engineers, 1 East 79th Street, New York, U.S.A.

Book Reviews

Servo-mechanisms

Servomechanisms *by* **P. L. Taylor.** *Longmans, Green & Co. Ltd. 1960. 418 pp. £2 2s.*

The advent of yet another introduction to the business of control engineering causes little stir these days: an amusing game can be played in which one determines the new arrival's place in a family tree descending from some august ancestor. Mr Taylor's book is essentially a new *Introduction*, being perhaps the first to present the components and techniques of automatic control systems without either assuming too much or insulting the reader's intelligence, and then introducing the theory based on a rigorous use of the complex variable. The publishers must also be congratulated on producing this profusely illustrated and well ordered book at such a reasonable price.

The author has set out to write an introduction to the practice and theory of linear feedback systems for students in search of a diploma or degree. Not only has he succeeded in this but he has also provided the physicist, chemist and other specialists with a book to browse in should they find themselves oscillating wildly after a first step-input of servo jargon. A particular point of interest is the collection of notes after each chapter should the student wish to meditate more deeply on the text, and there is a complete set of examples at the end of the book—with the answers.

The book is divided into three parts. Part I (three chapters) introduces the fundamental ideas behind automatic control and conducts a brief survey of computation and data transmission. Part II (ten chapters) examines from the control engineer's point of view the behaviour of the various elements with which servo-mechanisms are familiarly constructed. Detail has to be limited when the discussion includes static and rotary amplifiers, phase-sensitive rectifiers, electrical, hydraulic, and pneumatic machines. But there is more than enough for the uses and limitations of each component to be understood so that a transfer function for both command and disturbance may be derived. Part III (six chapters) deals with the theory, in particular that for the analysis of dynamic behaviour (design and synthesis are not covered). These chapters came as a welcome surprise and are alone worth the cost of the book. The analysis of the transient and harmonic response of a linear system is based on a model discussion of the theory of the complex variable. The result is a section on servo-analysis of unusual power for an Introduction, and a fitting close to a text that should be of great use to all students of control engineering.

P. K. M'PHERSON

Temperature

Temperature Measurement and Control *by* **W. F. Coxon.** *Heywood & Co. Ltd 1960. 314 pp. £3.*

The text is mainly derived from the *British Standard Code* (1041:1943) *on Temperature Measurement*, the *Instrument Manual*, Young's *Introduction to Process Control Systems Design*, and various manufacturers' publications. A book of this nature inevitably suffers in its construction, since the matter from diverse sources cannot be well balanced or bound together without gaps and repetitions unless it is completely rewritten. While the material from the B.S. Code and Young's book is reproduced almost word for word, attempts to paraphrase or abbreviate have led to several very unfortunate errors and ambiguities.

The first two chapters present rather a hotch-potch of data on the physics of heat and electricity and the principles of thermometric instruments, the latter often anticipating the content of later chapters in a perfunctory way. Chapters on the methods of thermometry are followed by descriptions of commercial instruments: these descriptions will be of practical interest to the budding control engineer and it is a pity that they are confined to so narrow a selection of manufacturers.

A chapter on automatic temperature-control deals with the basic elements of automatic systems and then describes a number of components and practical systems: these are all pneumatic, although the table of detecting and measuring elements refers mainly to those having electrical outputs. Finally some typical installations are described.

The many line drawings are well produced but the index is not adequate.

For a general introduction to the subject, this book serves its purpose, but its value is diminished by the occasional loss of accuracy suffered by the material in transcription.

K. M. GREENLAND

Computers

Digital Computer and Control Engineering *by* **Robert Steven Ledley.** *McGraw Hill Publishing Co. Ltd. 1960. 835 pp. £5 12s. 6d.*

The first thing to note about this book is that, to readers of *Control* at least, the title is more than commonly misleading. Only passing reference is made to the use of digital computers for control purposes, by way of illustration of their various applications, and a less confusing rendering of the title might be 'Digital Computers, their Logical Organization and Design'.

The book falls between two stools. As '. . . a comprehensive elementary engineering textbook . . .' it is of a length more appropriate to a work of reference, this being attributable to attempts at clarification by means of detailed examples rather than by an unencumbered exposition of fundamental principles. Thus, it is at once too long for students, and contains too much redundant matter for experienced practitioners. It should be said, too, that the techniques which are developed are applicable mainly to complex digital systems, and that logical designers who are interested only in small computers or lesser systems would be well advised to seek their background elsewhere.

Despite the fact that the mathematical presentation of basic theory tends to obscure its underlying principles, this formal approach is particularly elegant, and is aided by excellent diagrams and illustrations.

The text is divided into five main sections, the first of which, leading up to programming, is always a difficult subject to get over in general terms. This attempt is only partially successful, owing to the tendency to use too many examples, and these in a degree of detail which saturates the mind of the average reader. Starting with an excellent introduction to numerical analysis, the second section concludes the discussion of overall design by considering that of a particular computer invented by the author, subsequent sections being illustrated *ad nauseum* by its detailed design. The next two sections, dealing with logical design, open with a clear account of the necessary concepts of Boolean algebra, from which the method of design of optimum switching networks is developed. In the formal approach to the design of arithmetic units, there is a tendency to lose sight of the objective; for example, there is much detail on the best arrangement of gates in a parallel adder for a given carry propagation speed, but no mention of the techniques used to increase the carry speed itself. In contrast to the rest of the book, the last section, on electronic design, is confined to principles, with no examples of practical design, and appears to have been added for completeness rather than for usefulness. In summary, this book will appeal to the more theoretical among us who are involved in the overall logical design of complex digital systems.

R. A. MORLEY